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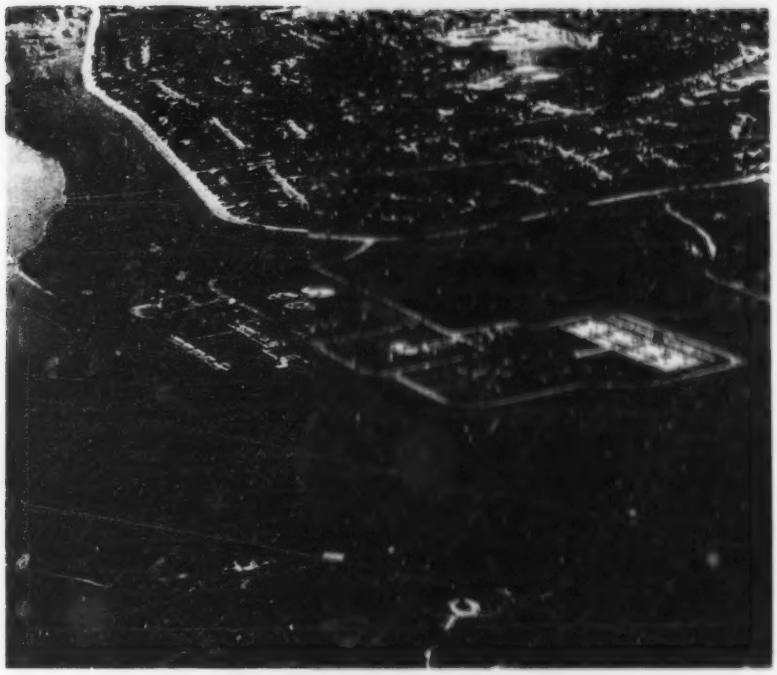

Ecological Survey of the South Saskatchewan River Downstream of the City of Saskatoon Wastewater Treatment Plant

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101-06607

Ecological Survey of the South Saskatchewan River Downstream of the City of Saskatoon Wastewater Treatment Plant

by

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National Library of Canada cataloguing in publication data

Constable, Miles

Ecological survey of the South Saskatchewan River downstream
of the City of Saskatoon wastewater treatment plant

Includes an abstract in French.
ISBN 0-662-30018-1
Cat. No. En40-622/2001E

1. Sewage—Environmental aspects—South Saskatchewan River.
2. Sewage—Environmental aspects—Saskatchewan—Saskatoon Region.
3. Water quality—Environmental aspects—South Saskatchewan River.
4. Water quality—Environmental aspects—Saskatchewan—Saskatoon Region.
5. Effluent quality—South Saskatchewan River.
6. Effluent quality—Saskatchewan—Saskatoon Region.
I. Canada. Environment Canada.
II. Title.

TD227.S3C66 2001 363.739'42'0971242 C2001-980208-0

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Acknowledgements

The chemical analyses of water and sediments were conducted by Environment Canada's Inorganic Chemistry Laboratory in Edmonton under the guidance of Rob Koski. The chlorophyll-*a* analyses were conducted by Gail Gray of Environment Canada's Nutrients Laboratory in Saskatoon. Bohdan Bilyj of BioTax in Guelph, Ontario, did the benthic macroinvertebrate identifications under contract. Materials and technical assistance were supplied by Dr. Pat Chambers and Trinh Luong of Environment Canada's National Water Research Institute in Saskatoon. Mr. C.P. Hwang, Manager of the City of Saskatoon Wastewater Treatment Centre, provided access to the river through its facility and historical data on its effluent quality. My able-bodied summer student was Darren Rath.

Cover photo: Saskatoon Wastewater Treatment Plant, courtesy of the City of Saskatoon.

Executive Summary

Ecological conditions of the South Saskatchewan River below the City of Saskatoon have been studied over the past 25 years to determine the causes of significant growths of nuisance algae and heavy growths of aquatic plants. The City of Saskatoon has periodically upgraded the level of treatment of its sewage effluents. In 1996, the city rebuilt the H. McIvor Weir Pollution Control Station to a state-of-the-art tertiary treatment system removing much of the biochemical oxygen demand (BOD), suspended solids, nutrients and minerals.

Several substances commonly found in Canadian municipal wastewater effluents have been assessed under Environment Canada's Priority Substances Assessment Program. These substances are: chlorinated wastewater effluents, inorganic chloramines, ammonia in the aquatic environment, nonylphenol and its ethoxylates, and textile mill effluents. Chlorinated wastewater effluents have been added to the List of Toxic Substances under the *Canadian Environmental Protection Act* (CEPA), 1988, and the other substances may be added under CEPA, 1999 in the near future.

In order to provide information to Environment Canada's risk management process for these substances regarding the possible benefits from a significant upgrade to a treatment system, Environment Canada's Edmonton office decided to conduct an ecological survey of the conditions downstream of the City of Saskatoon's wastewater discharge four years after its upgrade.

The results show that the benthic macroinvertebrates have responded in a positive manner, albeit in a subtle way. Insect populations were similar to those found in a 1994–1995 survey. There were more sensitive species in the river than found previously. Both surveys indicated that the insect community of the river did not conform to what is typically found below a sewage discharge high in organic matter. In the 2000 survey there was no pattern of community alteration between the upstream control site and the downstream potentially affected sites.

The concentrations of chlorophyll-*a* from attached algae were fairly high 150 m below the discharge; however, the density of the algal growth declined rapidly downstream. Growths of algae did not appear to be excessive anywhere.

The heavy macrophyte growths of previous years were not present. There were a few patches of aquatic plants along the shore, mostly found 15–26 km downstream. Based on previous work done on plants in this river, the reduction in growth may be a coincidental combination of scouring from floods in 1991–1992 and 1995 and the large reduction in nutrients and suspended solids. It remains to be seen if the macrophytes will come back; however, there were no significant areas of the fine sediments required by aquatic plants.

Water chemistry downstream of the discharge was not significantly different from upstream. The effluent had a Total Dissolved Solids concentration below that of the river. Conductivity could not be used to track the effluent plume, as is possible with a secondary treated effluent, as the mineral chemistry of the plume was not significantly different from that of the river. Some cations gradually increased in concentration downstream, as would be expected in a stream of basic pH on the Canadian prairie.

Wildlife in the river valley was abundant, with Canada geese, white pelicans, gulls, terns and cormorants being common.

Human use of the river was noted; activities were swimming, walking dogs, hiking, fishing, and canoeing.

Overall, the ecological conditions of the river are quite good. The City of Saskatoon does not appear to be having a significant ecological impact on the South Saskatchewan River.

Résumé

Depuis vingt-cinq ans, les conditions écologiques de la rivière Saskatchewan Sud en aval de la ville de Saskatoon font l'objet d'études pour définir les causes de la croissance importante des algues nuisibles et de la progression fulgurante des plantes aquatiques. La ville de Saskatoon a périodiquement modernisé ses installations de traitement des effluents et, en 1996, elle a transformé la station d'épuration H. McIvor Weir en une installation de traitement tertiaire à la fine pointe de la technologie, qui élimine une grande partie des charges en demande biochimique d'oxygène (DBO), des matières en suspension ainsi que des substances nutritives et minérales.

Plusieurs substances présentes généralement dans les effluents d'eaux usées des municipalités canadiennes ont fait l'objet d'évaluation dans le cadre du Programme d'évaluation des substances d'intérêt prioritaire d'Environnement Canada. Parmi ces substances, on compte les effluents d'eaux usées chlorées, les chloramines inorganiques, l'ammoniac dans l'environnement aquatique, le nonylphénol et ses éthoxylates ainsi que les effluents des usines de textile. Les effluents d'eaux usées chlorées ont été ajoutés à la Liste des substances toxiques en vertu de la *Loi canadienne sur la protection de l'environnement* (LCPE), 1988, et d'autres substances peuvent être ajoutées à la LCPE, 1999, dans un proche avenir.

Afin d'appuyer le processus ministériel de gestion des risques portant sur ces substances et de démontrer les avantages pouvant découler de l'amélioration d'un système de traitement, le bureau d'Environnement Canada à Edmonton a décidé de mener une étude écologique des conditions de l'eau en aval du rejet des eaux usées de Saskatoon, quatre ans après l'exécution des travaux.

Les résultats de l'étude indiquent que la situation de la faune macro-invertébrée benthique s'est améliorée, quoique d'une manière légèrement perceptible. Les populations d'insectes sont comparables à celles relevées dans une enquête menée en 1994–1995. La rivière contient maintenant plus d'espèces sensibles qu'auparavant. Les deux enquêtes révèlent que la population d'insectes de la rivière ne correspond pas à celle généralement présente dans les rejets d'eaux usées à forte teneur en matière organique. L'enquête effectuée en l'an 2000 fait ressortir qu'il n'y a pas de différence entre les populations d'insectes dans la zone témoin en amont et celles dans les zones potentiellement perturbées en aval.

La teneur en chlorophylle-*a* provenant des algues fixes est assez élevée 150 m en aval de l'effluent. Toutefois, la densité des algues s'atténue rapidement en aval de ce point. La progression des algues ne semble pas excessive à aucun endroit.

On ne remarque plus la présence abondante de macrophytes observée les années précédentes, mais il y a quelques parcelles de plantes aquatiques le long de la rive, principalement de 15 à 26 km en aval. Selon les enquêtes antérieures portant sur la flore de la rivière, la réduction de la croissance des plantes aquatiques serait attribuable à l'érosion causée par les inondations de 1991–1992 et de 1995 jumelée à la forte baisse de matières nutritives et en suspension. Il reste à surveiller si les macrophytes réapparaîtront; on n'a toutefois pas remarqué de zones importantes de sédiments fins nécessaires à la croissance des plantes aquatiques.

La composition chimique de l'eau en aval de l'effluent ne varie pas beaucoup de celle de l'eau en amont. La teneur totale en matières dissoutes de l'effluent est moindre que celle de la rivière. Les essais de conductivité électrique n'ont pas permis de retracer le panache de dispersion de l'effluent comme dans le cas de traitement secondaire, puisque la conductivité de l'eau du rejet est relativement semblable à celle de l'eau de la rivière. La concentration d'ions positifs s'accentue légèrement en aval, ce qui est prévisible dans le cas d'un cours d'eau basique dans les Prairies canadiennes.

La faune est abondante dans la vallée de la rivière. On y retrouve des outardes, des pélicans d'Amérique, des sternes, des guifettes et des cormorans.

Parmi les activités récréatives sur la rivière, mentionnons la baignade, la promenade de chiens, la randonnée, la pêche et le canotage.

Dans l'ensemble, les conditions écologiques de la rivière sont assez bonnes. Les activités de la ville de Saskatoon ne semblent pas avoir d'incidences écologiques importantes sur la rivière Saskatchewan Sud.

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1. Introduction

The South Saskatchewan River (SSR) is a wide, shallow river that originates at the junction of the Bow and Oldman rivers in Alberta. These two rivers descend from the Rocky Mountains and join downstream of Calgary. It then meanders across southern Alberta through Medicine Hat and turns northwest into Saskatchewan. Roughly 150 km upstream of Saskatoon the SSR is controlled by the Saskatchewan Power Corporation's Gardiner Dam to form Lake Diefenbaker.

Downstream of Saskatoon the river winds through a steep-sided valley covered with long grasses, shrubs and small trees. Large trees grow close to the river only in a few flat, depositional areas. River depth in summer is often less than ½ m, with sand bars and boulder fields making boat passage difficult. Access to the river is limited due to the steep banks; the closest publicly available boat launch to Saskatoon is at Clarkboro Ferry, 26 km downstream.

After considerable complaints from downstream users, the City of Saskatoon constructed the Spadina Comminutor System in 1948 to provide simple treatment (grinding) to its sewage, although much of the peak flow was still bypassed to the river. For the next 14 years the flow of the river was considered adequate to provide dilution for the raw sewage, assuming an average flow of 28.3 m^3/sec^{-1} (1000 cfs). In 1962, the City built the Stanley Anaerobic Stabilization Ponds to serve a portion of the City with sewage treatment to improve water quality through the city. Little improvement in water quality occurred and in 1968 during filling of Lake Diefenbaker there were many complaints of poor water quality, likely due to poor dilution of the effluent. In 1971, the H. McIvor Weir Pollution Control Plant came on-stream to provide primary treatment for the entire city. The anaerobic stabilization ponds and comminutor system were closed at this point (Tones et al. 1980). A periphyton and chemistry survey of the river below the discharge point was conducted to determine conditions prior to any further treatment (Tones et al. 1980). In 1983, the Province of Saskatchewan prompted the City to conduct a survey to determine its impact on the river, to assist in future sewage treatment upgrades. The City conducted a study focusing on chemistry and macrophyte growth and produced an internal report (City of Saskatoon 1985). In 1990 advanced phosphorus removal was initiated to reduce phosphorus concentrations in the river. Chambers (1993) conducted a study on the impacts of phosphorus removal on macrophytes in the river for the City of Saskatoon. Himbeault (1995) conducted a survey of benthic macroinvertebrates and periphyton downstream of the sewage treatment plant for a Masters thesis. In 1996, the City of Saskatoon rebuilt the sewage treatment plant at a cost of $50 million. It is now a state-of-the-art tertiary treatment plant with chlorine disinfection, almost total removal of suspended solids, removal of phosphorus, nitrification of ammonia and denitrification of nitrates.

This study was developed to provide input into Environment Canada's risk management process on the benefits of tertiary treatment to a typical prairie river. It focuses on chemistry, benthic macroinvertebrates, periphyton and macrophytes within the 26 km of the river from the sewage treatment plant to Clarkboro Ferry.

2. Background

2.1 Site Descriptions

Eight sites were chosen for this survey, with an additional water sample point at the outfall diffuser. The sample locations were chosen to maximize the number of samples taken immediately around the outfall where the majority of the environmental impacts would likely occur. Locations were 100 m upstream, and 150 m, 500 m, 1 km, 2 km, 5 km, 10 km and 26 km downstream (Figure 1). In May sites were chosen starting from Clarkboro Ferry (site 1) and traveling upstream by boat. A site was chosen when the correct distance had been traveled from Clarkboro Ferry as determined by GPS (a Garmin eMap® was used). All sites were chosen on the left side of the river (as determined when facing downstream), as historical studies have shown a discrete plume along that side. These sites also correspond quite well to historical sampling sites from various studies conducted on the river. They were numbered with site 1 at 26 km downstream at Clarkboro Ferry as that is where each sampling trip started, working upstream.

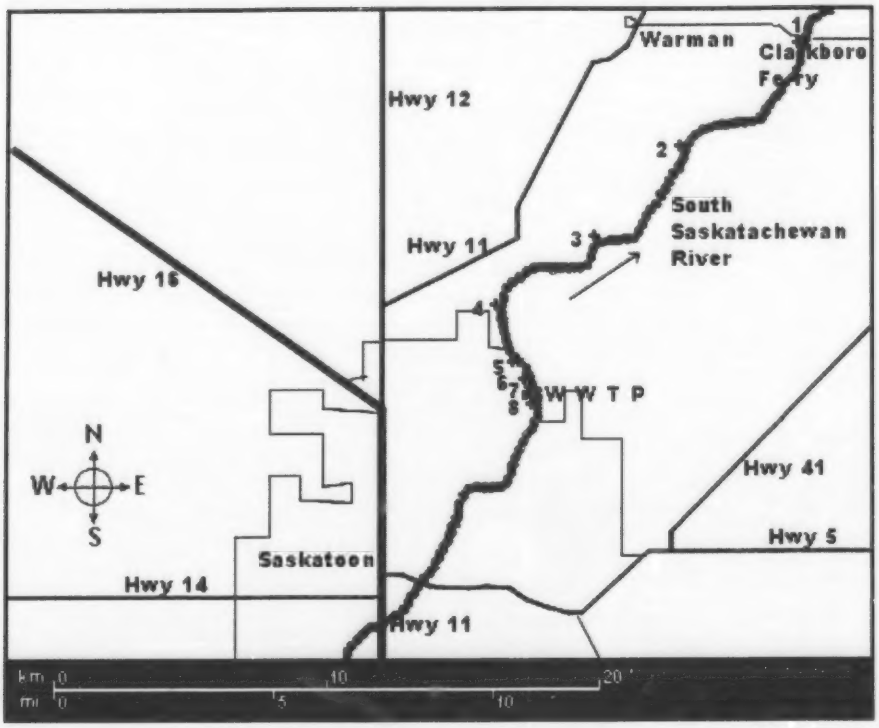

Figure 1. Site Map. ("WWTP" indicates the Wastewater Treatment Plant.)

Site 1, Clarkboro Ferry—26 km downstream

Site 1 is located roughly 26 km downstream of the Saskatoon WWTP outfall on the left side of the river (52° 19.195'N 106° 27.511'W) immediately upstream of the ferry-landing. It is at a small point of land on an outside curve of the river, although immediately below it is a partial obstruction of the river designed to back up water for the ferry. A rocky bottom with little sedimentary material characterizes site 1. It contained a gravel:sand:silt mix of 20:64:14%. It could be described as an erosional zone, from a sedimentary perspective. The current is slow due to the downstream obstruction.

Figure 2. Site 1 in August 2000

Site 2, 10 km downstream

Site 2 is located 10 km downstream of the WWTP outfall (52° 14.310'N 106° 31.301'W), or 16 km upstream of Clarkboro Ferry, on the left side of the river. It is immediately below a new acreage development called Cathedral Bluffs. Some construction activity was apparent in the river between June and August, with the addition of a surface water line run into the river. The bottom was principally sand (65%) with silt and a few rocks. This site is on a fairly straight stretch of river; based on the silt present, it would be a depositional zone.

Figure 3. Site 2 in August looking downstream.

Site 3, 5 km downstream

Site 3 is located 5 km below the WWTP outfall (52° 12.957'N 106° 33.998'W), 21 km upstream of Clarkboro Ferry, on the left side of the river on an inside bend. The site is located just east of the Wanuskewin Native Heritage Museum below an abandoned gravel pit. Access by foot is possible through the gravel pit. It is a rocky point of land that juts well into the flow of the river; consequently it has a continuously strong current and is an erosional zone. The bottom at site 3 was largely sand (75%) with rock and little sediment.

Figure 4. Site 3 in August looking downstream.

Site 4, 2 km downstream

Site 4 is located 2 km below the WWTP outfall (52° 12.210N 106° 36.755W), 24 km upstream of Clarkboro Ferry, just below the Phillips Pulp and Paper Chemical Co. site. It is a point of rocks on an outside bend of the river with a continuous strong current. It is an erosional zone with a rocky bottom with some patches of sediments. What little was there was primarily sand (73%).

Figure 5. Site 4 in August looking upstream.

Site 5, 1 km downstream

Site 5 is located 1 km below the WWTP outfall (52°11.395'N 106°36.806' W), 25 km upstream of Clarkboro Ferry, on the left side of the river on a straight stretch. It is a small rocky point of land with an erosion area upstream, and a shallow, marshy bench on the slope above it. The bottom was composed of fine silt on the upstream portion with rocks tending to the downstream section of the site. It was not apparent whether this was an erosional or a depositional site. Site 5 had a gravel:sand:silt composition of 21:44:29%.

Figure 6. Site 5 in August looking downstream.

Site 6, 570 m downstream

Site 6 was 570 m downstream of the WWTP outfall (52°11.211'N 106°36.497'W) on the left side of the river. It was a mixed sand/rock point of land on an outside bend in the river. Site 6 was characterized by a large boulder forming the downstream edge of the site and deadfall on the upstream side. The bottom was of heavy rock with some patches of sediment interspersed. Site 6 had a 60:30% mix of sand and silt.

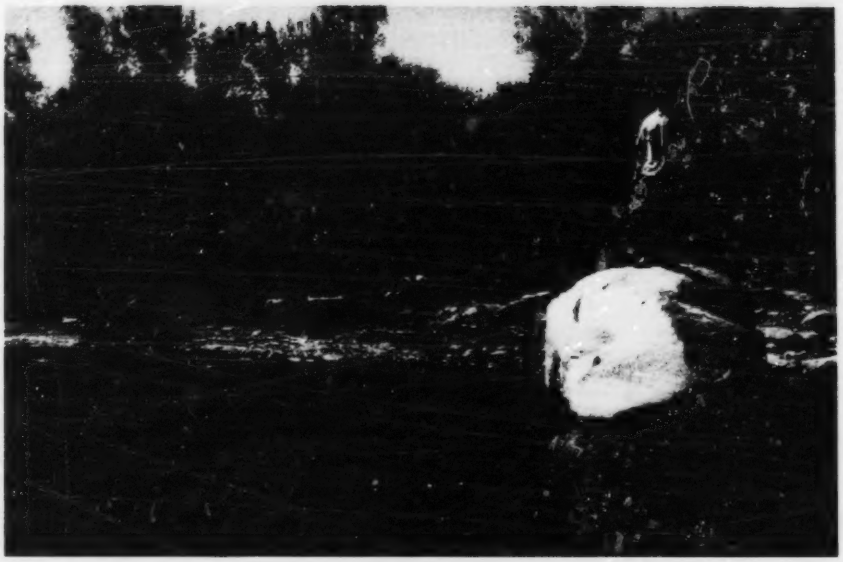

Figure 7. Site 6 in August looking towards shore.

Site 7, 150 m downstream

Site 7 was 150m downstream of the WWTP outfall (52°11.040'N 106°36.197'W) on the left side of the river, situated on a point of land such that the plume from the treatment plant could be seen to be crossing the point. It was a gradually sloping section composed almost solely of rocks with few sediments. It was an erosional zone composed mostly of sand (77%).

Figure 8. Site 7, looking upstream to the WWTP diffusers.

Site 8, 100 m upstream

Site 8 was located approximately 100m upstream of the WWTP diffusers on the left bank of the river. It acted as the control site for the study. It was on a small sandy point of land on a straight stretch of river. The bottom was primarily sand (85%) with many rocks. It could likely be described as a depositional area. The station can be seen just behind the second diffuser from the right in Figure 9.

Figure 9. Site 8 behind second diffuser on right, looking upstream.

Diffuser samples, 3 m downstream

For June to August, samples of water were taken from directly in front of the diffusers for chemical analyses. No other samples were taken at this location so it was not given a discrete sample number.

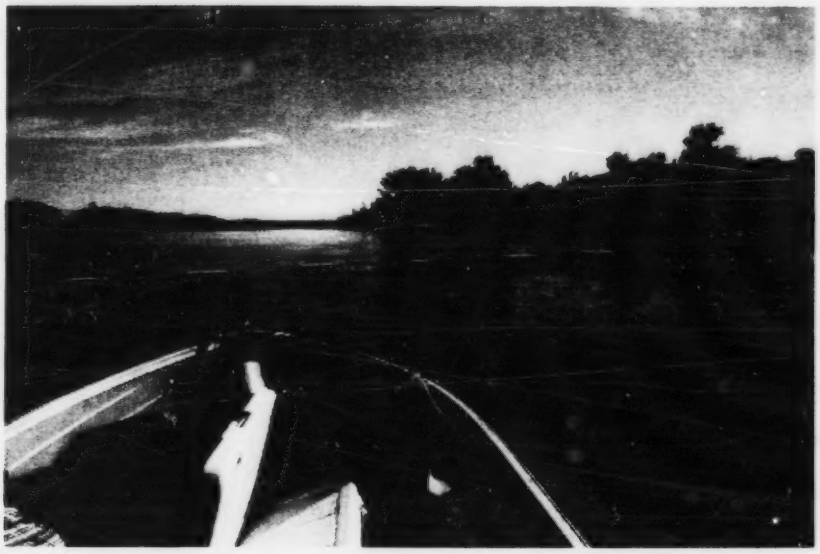

Figure 10. Diffuser sample location in August looking upstream.

2.2 Sampling Methods

2.2.1 Water

Water samples were collected as grab samples taken at approximately 0.5 m below the water surface upstream of the sediment/benthos sampling to avoid the suspended sediment created by that sampling. A sample was also taken immediately below the effluent outfall (within 5 m). Samples were stored in 1-L HDPE bottles in a cooler. At the end of the day the coolers were repeatedly filled with ice and kept cool until they were delivered to the laboratory.

2.2.2 Sediment

Sediment samples were collected with an Ekman dredge with a handle attached. As the areas being sampled were often rocky, it usually took multiple samples to collect 100g of sediments. The sediments were emptied onto the lid of a plastic pail and scooped into a pre-labeled Ziploc® plastic bag with a small shovel.

2.2.3 Periphyton

In May we collected three large rocks at random, scraped the obvious periphyton from the rock with a metal scoopula and put the sample into a 500-mL HDPE bottle. In subsequent sampling trips we removed all of the rocks from inside the Hess sampler and scraped them free of periphyton. The actual surface area of rock that was sampled varied, so this is a source of error in the values. Roughly 300–400 mL of river water was also put into the bottle to keep the periphyton alive. Two (2) mL of magnesium carbonate suspension was added to the sample to reduce degradation of the chlorophyll-*a*; as well, the bottle was immediately wrapped in aluminum foil to block out light and placed in the cooler.

2.2.4 Benthic Invertebrates

In May, due to the lack of a net for the Hess sampler, we collected sediment samples with an Ekman dredge and washed the sediments out of the sample using a large hand-held aquarium net. The apparent benthic invertebrates were collected from the net and placed into 70% denatured alcohol. We also collected three large rocks from the area and quickly placed them in a bucket to avoid the loss of invertebrates. We picked the invertebrates from the rocks with a knife or scoopula and placed them into the alcohol.

In three subsequent sampling trips we used a Hess sampler to collect invertebrates. The Hess sampler is a stainless steel cylinder 90 cm long, with a diameter of 36 cm (an area of 1017 cm^2, just over 0.1 m^2). The body of the cylinder has two 22 x 35 cm openings, one covered with stainless steel screening. The other opening has a lip projecting out from the cylinder; around this opening is tied a conical sampling net (mesh size of 500 µm) with a removable sampling jar at the end. The screened opening is positioned upstream, the net is tied on and the sampler is placed at random in the site. It should be forced quickly into the sediments if possible to avoid the loss of more mobile species.

All of the rocks within the Hess sampler were first removed and placed into a pail and taken to shore. Then the sediments within the barrel of the Hess sampler were vigorously stirred/dug up for roughly three minutes. The suspended sediment in the barrel of the Hess sampler was allowed to clear and we then carefully removed the collection net from the sampler, being careful not to lose any invertebrates. The net was washed down to push any invertebrates caught on the net into the collecting jar, although with Chironomids this was rarely successful as they quickly attach themselves to the netting. When this happened it was necessary to pick them off the net. If the sample had relatively little debris, the entire sample was placed into alcohol by washing it with alcohol through the drain hole in the collecting jar. If there was a lot of debris, the net and sample bottle were emptied into a pail and sequentially washed with river water, with the water being poured back through the sample jar to collect the invertebrates. Most of the contents were carefully removed with a scoopula and placed into alcohol, then the sample jar was rinsed off into the sample container with a spray bottle filled with alcohol. This technique worked well given 10–20 washings with river water. Any invertebrates left in the pail were removed and put into alcohol. The collected rocks were then carefully examined and the invertebrates were picked off with a knife or scoopula and placed into alcohol; the same rocks were used for the periphyton samples. The rocks were not put back into the river in case we inadvertently sampled them on another trip.

2.2.5 Macrophytes

In May there were few macrophytes in evidence. In subsequent trips, samples of macrophytes were collected by removing the entire above-sediment portions and placing them into a Ziploc® bag for later identification. Extent of macrophyte beds was estimated visually; no samples were taken to estimate growth density, as so few macrophytes were found that it would be meaningless.

2.2.6 Physical Parameters

Temperature, pH, dissolved oxygen and conductivity measurements were taken on each trip from each sampling site, upstream of where sediment and benthos sampling was conducted to avoid suspended sediments from that sampling. In June, July and August these parameters were also recorded from immediately below the effluent outfall. In May, July and August a HydroLab® was used; in June a set of individual meters was used. Dissolved oxygen and temperature were measured with an Oakton® DO100 Dissolved Oxygen/°C meter; conductivity and temperature were measured with an Oakton® CON400 meter; and pH and temperature were measured with an Oakton® pH meter. For temperature, if one meter was more than 2°C different from the others, that value was not recorded; otherwise an average temperature was recorded.

2.3 River Flow Rate

Gardiner Dam, 150 km upstream of Saskatoon, was completed in 1967 and was filling in 1967–1968. Since 1968 the flow regime of the SSR has been greatly changed. The spring–early summer flows are used to fill Lake Diefenbaker, so the typically high flows that occurred from April to July now rarely occur. The highest flows now are from December to February. The minimum objective riparian flow at Saskatoon is 42.48 m^3/sec (1500 cfs) (Waite 1977). Less than 1% of the flow at Saskatoon comes from the land between the dam and the city (Tones et al. 1980).

Average June flows prior to 1968 were 800 m^3/sec (with a range of 425–1150); they now average 215 m^3/sec (with a range of 45–395). January flows were the lowest, averaging 69 m^3/sec (with a range of 30–105); now they average 303 m^3/sec (with a range of 225–375) (see Figure 11 below). The variability in flow rate has also changed. June mean flows were rarely below 400 m^3/sec, whereas now the lowest mean monthly flow appears to be below the minimum required of 42.48 m^3/sec and has yet to rise to 600 m^3/sec. By comparing summer (April–August) flows from 1952 to 1996 it is apparent that in many years the summer flow regime now resembles a continuous drought situation with flows rarely exceeding 100 m^3/sec. Prior to the dam, summer flows were highly variable in size, duration and timing, with some truly large floods occurring (the maximum daily flow rate was 3940 m^3/sec on June 15, 1953). The most recent high water event at Saskatoon was in 1995 when a flow rate of 1280 m^3/sec peaked on June 11 (HYDAT 1999). The peak flow of 5200 m^3/sec at Medicine Hat was reduced to 1200 m^3/sec downstream of the Gardiner Dam (Figure 12). Without Lake Diefenbaker and the Gardiner Dam, flooding in the Saskatoon area would have been extensive, similar to what happened in Medicine Hat.

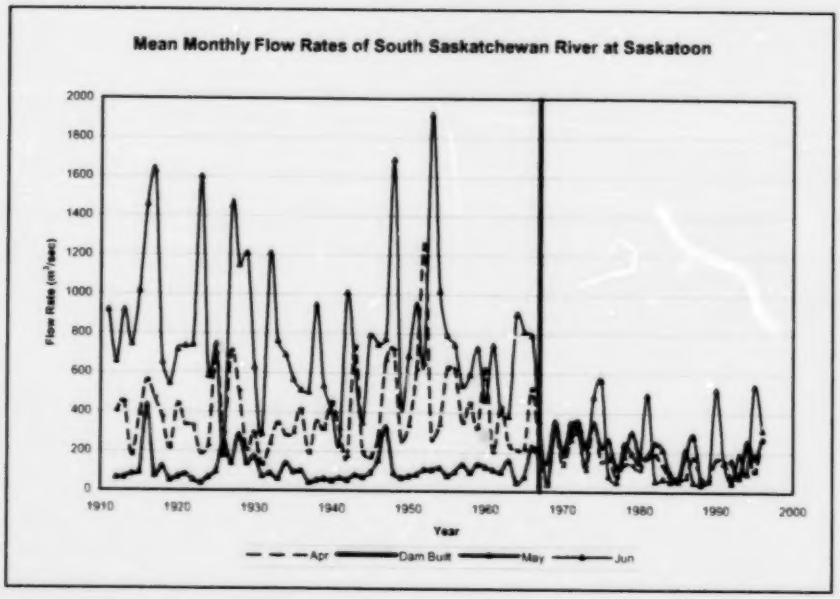

Figure 11. Mean Monthly Flow Rates of South Saskatchewan River at Saskatoon before and after the Gardiner Dam was installed.

The overall effect of the dam has been to invert the flow pattern, with very low spring and summer flows and higher winter flows with greatly reduced size, duration of high water events and variability. Of course, flooding around Saskatoon has been greatly reduced, which has benefited people living along the river. However, this severe alteration of the flow regime is likely to have impacts on the river ecosystem.

At a flow rate of 62.3 m^3/sec (2200 cfs), the time of travel from the WWTP outfall to Clarkboro Ferry is 15 hours (Tones et al. 1980).

The H. McIvor Weir is a flow control structure within the city of several metres in height. The weir was built to raise the water level within the city for recreational purposes and to create a body of water for municipal water withdrawals. It is located 5.4 km above the sewage treatment plant (see Figure 13 below).

Figure 12. Gardiner Dam Spillway, June 1995.
(Photo: Department of Geological Science, University of Saskatchewan)

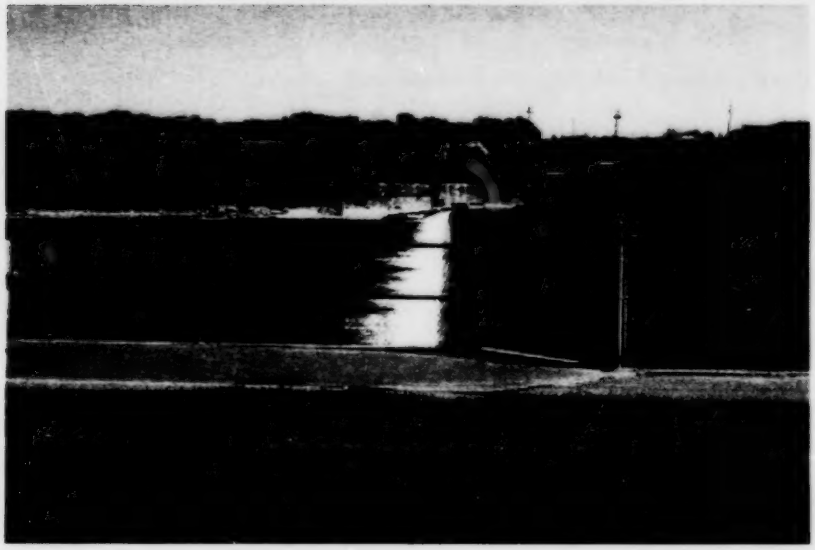

Figure 13. H. McIvor Weir in Saskatoon.

2.4 Human Use of the River

In the City of Saskatoon River Study (City of Saskatoon 1985), it was reported that human use of the river downstream of the sewage effluent outfall was minimal due to the rugged shoreline preventing access, and degraded water quality creating an unpleasant experience. Then, as now, the only public place to launch a boat near Saskatoon below the weir is at Clarkboro Ferry. In this study, however, considerable human contact with the river was in evidence. A new housing development along the riverbank, Cathedral Bluffs at site 2, provides residents with ready river access. Several jet boats were seen moored below the properties as well as at other locations. Children were seen swimming below the right bank at a farm, people were observed along the river east of the Wanuskewin Native Heritage Park near site 3, a large school group was encountered canoeing from the park above the sewage treatment plant, a environmental consulting company was monitoring construction activity above the sewage treatment plant, and numerous people with dogs were encountered on paths below the sewage treatment plant. There was considerable evidence (fire pits, line poles, beer bottles, trails, etc.) of people walking, biking and fishing immediately below the sewage treatment plant, while at Clarkboro Ferry there was considerable fishing activity. This evidence indicates that access is now probably the major deterrent to more human use of the river below Saskatoon.

Farms located along the river all have a water withdrawal pipe, as do the houses at Cathedral Bluffs and other locations along the river. Homeowners along the left bank have constructed a few wharfs.

2.5 Wildlife in the Valley

While not part of the study, it was easy to spot wildlife all along the river from the weir in Saskatoon to Clarkboro Ferry. Canada geese were successfully nesting all along the riverbanks from the Wanuskewin Native Heritage Park to Clarkboro Ferry, based on the large number of young and adults seen on the banks and sandbars and flying overhead. Adult and young white pelicans were also numerous, fishing at the weir, resting on sandbars and rocks, and fishing in the shallows along the riverbanks all along the river. Gulls and terns were also abundant, nesting and resting on most sandbars; cormorants were relatively less evident, although they were spotted on most sampling trips. Hawks were occasionally seen hunting over the river valley. Evidence of beavers (relatively fresh-cut trees and sticks) and several muskrats were spotted along the left bank, and whitetail deer and a coyote with young were seen along the right bank. Cattle were evident at several locations along the river, particularly just upstream of the railway bridge near Clarkboro Ferry.

3. Biosurvey Design

3.1 Advantages of Using Periphyton

Algae generally have rapid reproduction rates and very short life cycles, making them valuable indicators of short-term impacts.

- As primary producers, algae are most directly affected by physical and chemical factors.
- Sampling is easy, inexpensive, requires few people, and creates minimal impact on resident biota.
- Relatively standard methods exist for evaluation of functional and non-taxonomic structural (biomass, chlorophyll measurements) characteristics of algal communities.
- Algal assemblages are sensitive to some pollutants that may not visibly affect other aquatic assemblages, or may affect other organisms only at higher concentrations (e.g. herbicides) (Barbour et al. 1999).

3.2 Advantages of Using Benthic Macroinvertebrates

Macroinvertebrate assemblages are good indicators of localised conditions. Because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, they are particularly well suited for assessing site-specific impacts (upstream–downstream studies).

- Macroinvertebrates integrate the effects of short-term environmental variations.
- Most species have a complex life cycle of approximately one year or more. Sensitive life stages will respond quickly to stress; the overall community will respond more slowly.
- Macroinvertebrates are relatively easy to identify to family; many "intolerant" taxa can be identified to lower taxonomic levels with ease.
- Benthic macroinvertebrate assemblages are made up of species that constitute a broad range of trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects.
- Sampling is relatively easy, requires few people and inexpensive gear, and has minimal detrimental effects on the resident biota.
- Benthic macroinvertebrates serve as a primary food source for fish, including many recreationally and commercially important species.
- Benthic macroinvertebrates are abundant in most streams. Many small streams (first and second order) which naturally support diverse macroinvertebrate fauna, support only limited fish fauna (Barbour et al. 1999).

3.3 Habitat Assessment

The issue of reference conditions is critical to the interpretation of biological surveys. The reference condition establishes the basis for making comparisons and for detecting use impairment; it should be applicable to an individual water body, such as a stream segment, but also to similar water bodies on a regional scale.

There are three problems with site-specific reference conditions: (1) because they typically lack any broad study design, site-specific reference conditions possess limited capacity for extrapolation—they have only site-specific value; (2) usually site-specific reference conditions allow limited variance estimates; there are too few sites for robust variance evaluations because each site of concern is typically represented by one to three reference sites; and (3) the result could be an incorrect assessment if the upstream site has especially good or especially poor habitat or chemical quality.

The advantages of measuring upstream reference conditions are: (1) if carefully selected, the habitat quality is often similar to that measured downstream of a discharge, thereby reducing complications in interpretation arising from habitat differences; and (2) impairments due to upstream influences from other point and non-point sources are already factored into the reference condition (Barbour et al. 1999).

To meaningfully evaluate biological condition in a design such as this, sampling locations must be similar enough to have similar biological expectations, which, in turn, provide a basis for comparison of impairment. As the goal of this assessment is to evaluate the ecological effects of effluent chemistry improvement, comparable physical habitat must be sampled at all stations, otherwise the differences in the biology attributable to variable habitat will be difficult to separate from those resulting from water quality.

3.4 Benthic Invertebrate Assessment Techniques

The basis for conducting diversity analyses of the benthic invertebrate community is founded in aquatic ecology theory. All means of determining a community's "diversity" have strengths and weaknesses; indeed, there is considerable controversy in ecological research about the meaning and importance of such a term as "diversity". The old school of thought on the subject was that a diverse assemblage of species was considered to be more stable in an ecological sense than an assemblage of a few species. More recent ecological thought has drifted towards the concept of ecosystems, especially in rivers, as a continuum of species adapting to sources of energy available in the system as well as responding to conditions in the river. Vannote et al. (1980) called this the river continuum concept. Natural aquatic communities, those largely unaffected by humans, are typically characterized by the presence of a few species with many individuals and many species with a few individuals (Welch 1980) and have a high diversity index regardless of the indexing system used. The distribution of taxa within the community is important, as diversity indices cannot distinguish between pollution-tolerant and -intolerant organisms. A severely affected site can have the same diversity value as an unaffected site, but with greatly different organisms present (Lydy et al. 2000). Affected communities in the vicinity of poorly treated sewage outfalls typically have a large number of individuals of a few species that are adapted to tolerate low oxygen and able to use the large amounts of organic matter (Reynoldson 1973; Welch

1980; Hart and Fuller 1974). Often present are large numbers of worms of the genera *Limnodrilus* and *Tubifex* and certain species of midges of the family Chironominae. This adaptive phenomenon does not mean that any site with *Limnodrilus, Tubifex* and Chironomids is necessarily affected; these species are also present in unaffected communities (Hart and Fuller 1974), but under such adverse conditions they are often the only ones that can tolerate the conditions and can thrive. The worms dwell in the sediments and consume bacteria in them. They also have a high reproductive capacity to make up for the increased mortality inherent in a highly stressful environment (Hart and Fuller 1974). Unaffected communities in similar habitats typically have a large number of individuals of a few species that are adapted to high-oxygen conditions and moderate energy sources, usually generated from natural sources within and along the stream-banks (leaves and debris, etc.). Typical species found are in the orders Trichoptera (caddisflies like *Ceratopsyche sp.* and *Hydropsyche sp.*) and Ephemeroptera (mayflies like *Heptagenia sp.* and *Ephoron sp.*). Such clean water environments also have a large number of species with either a moderate number of individuals or a few individuals occupying various niches within the stream habitat.

Lydy et al. (2000) discovered that no single index would suffice to describe the improvements noted in benthic invertebrate communities when a sewage treatment plant was upgraded. For this project, we decided to use a selection of indices. For the analysis of benthic invertebrate community diversity, it was decided to use Simpson's Diversity Index as recommended by Washington (1984). Simpson's Diversity Index determines the probability of finding two organisms selected one after the other from different species. A high number indicates a high probability that the individuals selected are from different species. This indicates that the sample contains many species and is, therefore, highly diverse.

A second index, Chandler's Biotic Score, was used to analyze the community structure (Chandler 1970). It is based on assessing the benthic invertebrate community by the species' sensitivities to environmental conditions. The most sensitive species, typically found in the orders Trichoptera (caddisflies) and Plecoptera (stoneflies), are rated on an ascending scale so that increasing numbers in these orders give higher scores to the site. The least sensitive species, such as worms of the genera *Nais* and *Tubifex*, are rated on a descending scale so that increasing numbers of them give a lower score. Other orders, such as the Ephemeroptera (mayflies), are divided depending on the sensitivities of various species or types. For instance, mayflies of the genus *Baetis* are considered less sensitive than other genera, and biting flies of the genus *Simulium* are more sensitive than the other Dipterans. Once the numbers of the rated groups are determined, all of the numbers for the site are summed. This sum provides an idea of the structure of the community based on its sensitivity to environmental conditions. A high number, over 1000, would indicate that there are relatively large numbers of highly rated organisms (case-making caddisflies, stoneflies, and mayflies for example). There could still be large numbers of Chironomids and Oligochaetes present, but even large numbers would add little to the total score. This situation is often seen in unaffected situations in rivers, and is therefore considered to be natural. The caveats, as with other methods, are that similar habitats must be sampled at similar times and in similar ways. Also, some species present in the South Saskatchewan River are not rated in Chandler's scheme.

Species Richness is a simple test of the number of species present and an extrapolation of the graph generated from their numbers. From this, an estimate can be made of the number of species potentially present.

A computer program, Species Diversity and Richness (SDR, by Pisces Conservation Inc., 2000), was used to conduct most of these analyses, including determining the distribution of the raw data. All data sets fit a truncated log normal distribution. Simpson's reciprocal index (1/D) is calculated; from there a spreadsheet was used to convert this value into the Diversity Index (1–D). The SDR program also calculated the 95% confidence limits around the Diversity Index values, as well as conducting a two-tailed t-test for the significance between site values. SDR was also used to calculate Species Richness estimates.

Biotic Scores, Diversity Indices and Species Richness do not tell the whole story; the community of species was compared with typical sewage-affected communities from similar rivers. Where possible, the community structure of the South Saskatchewan River in 2000 was compared to the same stretch of river sampled in 1994 by Himbeault (1995). Unfortunately, this was the only other reference found to the community structure of the benthic invertebrates below Saskatoon. Himbeault's study was not done as a baseline for future studies, and so did not sample the complete benthic invertebrate community. Lehmkuhl (1972) described the impact of the

Gardiner Dam on the benthic invertebrates between the dam and Saskatoon, but he did not continue below the city due to assumed impact from the sewage effluents. The distribution of species in the river was also compared to other studies of similar systems, in particular to the study by Reynoldson (1973) on tributaries to the Saskatchewan River in Alberta, the situation around Edmonton on the North Saskatchewan River (Golder Associates, 1995) and to similar situations on the Cowichan River (Perrin et al. 1988).

4. Data Analysis

4.1 Benthic Macroinvertebrates

Raw data from the benthic invertebrate samples are presented in Appendix I.

4.1.1 May

As stated earlier the May samples were collected with a more primitive technique than was used during June to August; therefore, some of the differences present in the May samples may have been the result of this difference in sampling.

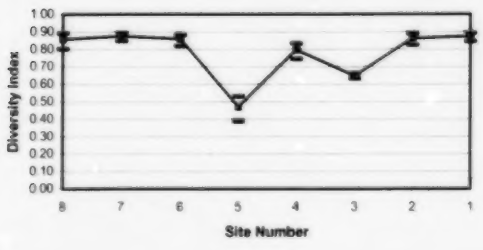

Figure 14a. Simpson's Diversity Indices with 95% CL—May

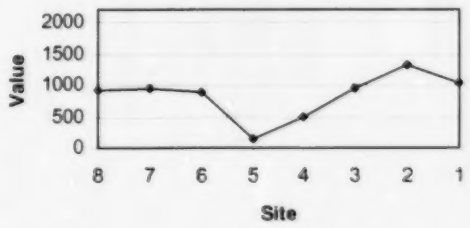

Figure 14b. Chandler's Biotic Scores—May

Table 1. Similarity Matrix of Diversity Indices for May —2 tailed t-test

Site	7	6	5	4	3	2	1
8	No	Yes	No	No	No	Yes	Yes
7		No	No	No	No	Yes	Yes
6			No	No	No	Yes	Yes
5				No	No	No	No
4					No	No	No
3						No	No
2							Yes

Analysis of the diversity data does not reveal any trends. Most of the sites have consistently high diversity—generally over 0.8—with sites 5 and 3 being much lower (down to 0.47). T-tests reveal that sites 8, 6, 2 and 1 are similar in diversity, although site 7 is significantly higher in diversity.

Chandler's Biotic Scores are presented in Figure 14b. All sites except 5 and 4 were very high. An analysis of the species showed that 8, 7 and 6 were all very similar, with between 141 and 285 individuals sampled from 24 to

27 species. There were no predominantly abundant species. There was a wide variety of organisms with many representatives of worms, mayflies, stoneflies, caddisflies and flies (especially midges), and there were a few representatives of shellfish and snails. Site 5 is very different, with only 4 species present, these being predominantly the worm genus *Limnodrilus*, and the snail genus *Pisidium*. There were also a single stonefly and a few midges (Chironomidae). Chandler's Biotic Score for site 5 is suitably low, and could indicate a severely affected site, although this reduction in species and numbers may well be an artifact of sampling and a slightly different habitat from most of the other sites. The habitat at site 5 is more of a depositional zone, with more mud and plants and fewer rocks. Site 4 had only 139 organisms from 17 species, but the distribution of organisms in those 17 species was fairly even, thereby maintaining a high diversity, although a relatively low Biotic Score. Site 3 had 1960 individuals in 28 species. The midge *Chironomus sp.* predominated, and the worms *Limnodrilus sp.* and *Nais sp.* were also well represented. More mud and fewer rocks also characterized the habitat at site 3, so this difference could explain the unequal species distribution and lower diversity. The Biotic Score, however, is as high as upstream, indicating a good mix of organisms. Sites 2 and 1 had high diversity with a mixed assemblage of organisms, with no one species predominating; the Biotic Scores are suitably high.

Species Richness estimates indicated a potential community of 73 species, based on 58 found in our May samples.

4.1.2 June

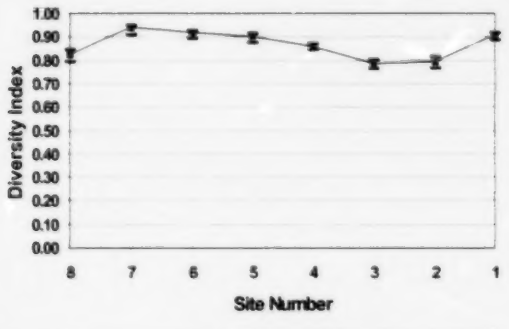

Figure 15a. Simpson's Diversity Indices with 95% CL—June

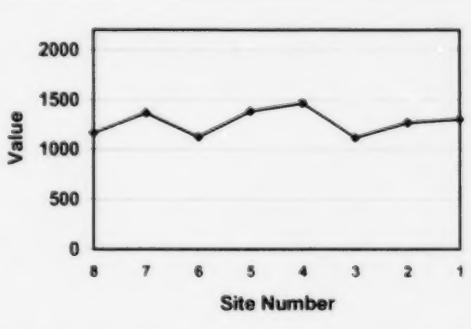

Figure 15b. Chandler's Biotic Scores—June

Table 2. Similarity Matrix of Diversity Indices for June—2 tailed t-test

Site	7	6	5	4	3	2	1
8	No	No	No	No	No	No	No
7		No	No	No	No	No	No
6			No	No	No	No	Yes
5				No	No	No	Yes
4					No	No	No
3						Yes	No
2							No

June Diversity Indices were all quite high, ranging from 0.78 to 0.94. There was a general trend of declining diversity from site 7 to site 2, with sites 8 and 1 not falling within this pattern. This may be coincidental, as there is no logic in such a pattern. The highest diversity is found at the site that should be affected the most, number 7, which is 150 m below the outfall; diversity then declines downstream when it should be increasing.

Comparing the Diversity Indices with a t-test shows that sites 8, 7 and 4 are not similar to any other site, while sites 6 and 5 are similar to 1, and sites 3 and 2 are similar.

Some new species show up in the June samples, perhaps as a result of the different sampling technique. A good example is the appearance of the Mermithidae, a family of parasitic nematodes that live on insects and that are present in all samples from June to August. Representatives of Cladocerans, Copepods, crayfish, and mites are all captured starting in June. Also, the mayflies, stoneflies, caddisflies and midges are better represented in numbers and species with the use of the Hess sampler. The biodiversity of site 3 is significantly below the other sites, although it had 1110 individuals from 33 species. This is explained by the preponderance of the mayfly *Baetis sp.* (448 individuals) and a stonefly genus *Ceratopsyche* (224 individuals) in the sample. The Biotic Score is relatively low compared to some of the other sites, as *Baetis* is scored low due to its tolerance for pollutants; but the large number of stoneflies raises the score. There is a fairly even distribution of numbers across the other species present with all of the major groups of macroinvertebrates represented, as is reflected in the Biotic Score. Site 2 was also significantly less diverse than the other six sites, with 570 individuals from 34 species. This was because of a preponderance of the worm genus *Limnodrilus* and the mayfly genus *Baetis*, with a reduction in numbers of individuals of other species. Site 4 was very similar to sites 2 and 3, in that it had a lot of individuals (1246) spread over 40 species. However, it had a more equitable distribution of those species with high numbers of the mayflies *Baetis sp.* and *Heptagenia sp.*, the stonefly genus *Ceratopsyche*, and many other species with moderate abundance (~ 50 individuals each). Site 7 had significantly higher diversity than the other sites with a small number of individuals (114) spread over 34 species in all of the major orders.

Species Richness estimates were 90 species based on the homogeneous distribution of 73 species in the samples.

4.1.3 July

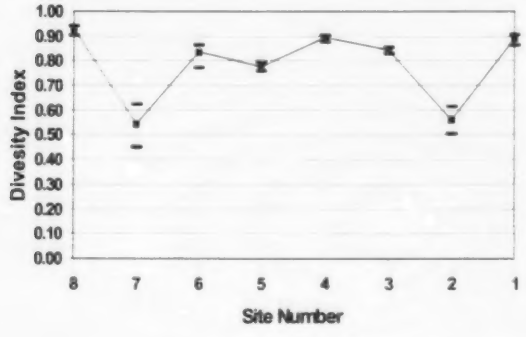

Figure 16a. Simpson's Diversity Indices with 95% CL—July

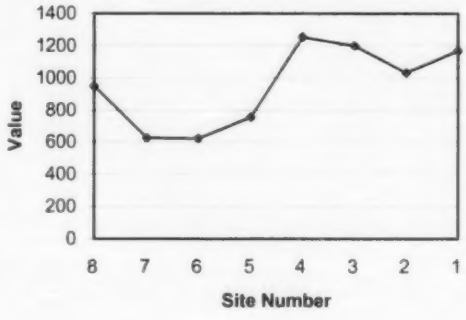

Figure 16b. Chandler's Biotic Scores—July

Table 3. Similarity Matrix of Diversity Indices for July—2 tailed t-test

Site	7	6	5	4	3	2	1
8	No	No	No	No	No	No	No
7		No	No	No	No	Yes	No
6			No	No	Yes	No	No
5				No	No	No	No
4					No	No	Yes
3						No	No
2							No

The benthic invertebrate data were more variable in July, perhaps due to the differences in habitats beginning to show. The Diversity Indices ranged from 0.54 to 0.93, with sites 2 and 7 being the lowest. The reference site (8) was rather impoverished in numbers in July, with only 166 individuals representing 30 species present; however, this gave it a very high Diversity Index of 0.92. Sites 7, 6, and 5 were depleted in mayflies, probably due to emergence, and had relatively large populations of *Limnodrilus sp.*, unlike previous months. Site 4 was not much different in July, although the high numbers of a few mayflies were reduced, again likely due to emergence. The pattern of benthic abundance at Site 3 shifted in July, having a diverse assemblage of organisms but being dominated by two mayflies—*Baetis sp.* and *Ephoron album*—and a caddisfly, *Ceratopsyche sp.* It appears that the life cycles for *Baetis* and *Ceratopsyche* were delayed at site 3, as they were abundant at many sites the previous month. Flies and midges (Dipterans) were also well represented, without any being dominant. Site 2 had a low Diversity Index in July, due primarily to the dominance of *Limnodrilus* in the sample. Other than having low numbers of many species, site 1 at Clarkboro Ferry had a very even distribution of organisms with a slight preponderance of the worm *Nais sp.* in the sample.

The similarity matrix does not show any particular pattern. Sites 8 and 5 are not similar to any other site. Sites 6 and 3, 7 and 2, and 4 and 1 were similar in diversity. The confidence intervals around the diversity values for sites 7, 6 and 2 were larger than in previous months.

The Species Richness estimate was 88 species based on the homogeneous distribution of 66 species in our samples.

4.1.4. August

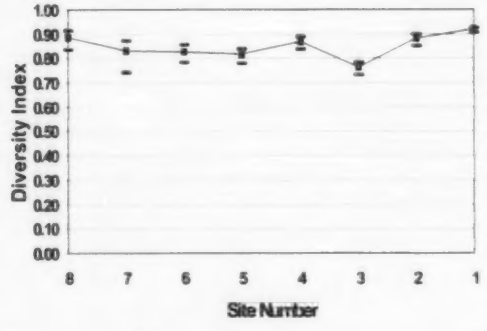

Figure 17a. Simpson's Diversity Indices with 95% CL—August

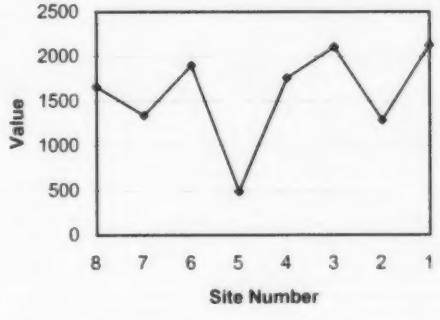

Figure 17b. Chandler's Biotic Scores—August

Table 4. Similarity Matrix of Diversity Indices for August—2 tailed t-test

Site	7	6	5	4	3	2	1
8	No	No	No	Yes	No	Yes	No
7		Yes	Yes	No	No	No	No
6			Yes	No	No	No	No
5				No	No	No	No
4					No	Yes	No
3						No	No
2							No

August numbers, overall, were down in most samples. Diversity Indices were uniformly high with little variation, ranging from 0.76 to 0.92, although species numbers per site ranged from 17 to 39. A species showed up throughout most of the sites that had only sporadic presence before. This was *Cambarincola sp.*, a leech-like worm that is commensal on crayfish (Clifford 1991). Coincidentally, the numbers and distribution of crayfish (*Orconectes virilis*) were up in most sites. Observation showed large numbers of immature crayfish under rocks at this time, as well as a few adults undergoing ecdysis (shedding the exoskeleton).

The reference station at site 8 had a relatively small community, with only 133 individuals in 27 species. The only real change in community composition was the presence of six species of caddisflies, where before only two had been found. Chandler's Biotic Score was high. Site 7 had very depressed numbers, with only 62 individuals of 17 species; still, the Diversity Index was high at 0.83 and the Biotic Score was moderately high. This is due to the individuals being spread over the 17 species fairly evenly; there was also a greater number of caddisfly species. Site 6 was similar in diversity and composition, caddisfly species were increased and mayflies were decreased. Site 5 was impoverished in August; note the low Biotic Score, with only 115 individuals in 12 species being collected. Flies and midges were largely absent; still, diversity was high at 0.82. Site 4 had a Diversity Index of 0.87, with 217 individuals in 26 species with a high Biotic Score. Again, fly and midge species were reduced in numbers. Site 3 had the lowest diversity in August at 0.76 with 996 individuals in 33 species, but it had the highest Biotic Score measured, over 2000. Flies, midges and mayflies were also reduced in numbers and species, while caddisflies were increased in abundance. Site 2 had a high Diversity at 0.88 with 208 individuals spread evenly over 27 species, but a rather low Biotic Score, around 1200. The species were also well distributed over the typical orders. Finally, site 1 in August was fairly typical of the other sites, with high Diversity (0.92, 639 individuals over 39 species) and a high Biotic Score. Flies and midges were somewhat increased in numbers, while mayflies and caddisflies were not changed. The one order that was unusually abundant was the Gastropods (snails), with at least four species and one (*Valvata tricarinata*) being particularly abundant compared with other sites and dates. This may have been due to the greater abundance of aquatic macrophytes at Clarkboro Ferry than at other sites.

There was no discernable pattern again in the diversity or biotic indices, judging by Figures 17a, 17b and Table 4. The reference site (8) was statistically similar in diversity to sites 4 and 2, while site 7 was similar to sites 6 and 5. Sites 3 and 1 were not similar to any other site.

Species Richness was estimated at 85 species, based on a homogeneous community of 65 species captured.

4.1.5 Comparison with Other Studies

Lehmkuhl (1972) found that the mayfly community below the Gardiner Dam was greatly impoverished from that above Lake Diefenbaker. His hypothesis was that the cold water withdrawn from the hypolimnion of the lake was altering the thermal regime of the river to the point where many species of mayflies could not complete their life cycle. He documented impacts down to Saskatoon. He did not continue beyond the city, for his results would have been confounded by the impacts from the sewage treatment plant. In an earlier incidental paper (Lehmkuhl 1970) he described the mayfly community of the river around Saskatoon. He described finding fungal-infected caddisflies, mayflies and stoneflies, some of which had failed to moult

properly and had severe damage to sensitive gills. None of the organisms collected in this survey displayed any of these signs of damage or infection.

Himbeault (1995) is the only other study directly coincident with this one on the macroinvertebrate community in the South Saskatchewan River. In his thesis he conducted a comparison of the Ephemeroptera, Plecoptera and Trichoptera numbers to the Chironomid numbers in an attempt to identify impacts. This approach is used in rapid bioassessment protocols to give a quick feel for the "health" of a benthic community. Lydy et al. (2000) found that the percentage of Ephemeroptera, Plecoptera and Trichoptera (EPT) in samples accurately reflected the changes in the benthic community following an improvement in nearby sewage treatment. To use this approach, the sampling must be done carefully with respect to site and timing, as the presence of many aquatic insects changes dramatically over short periods as they mature and emerge from the river as adults.

Three of Himbeault's sites are directly comparable to this study: UP1 is equivalent to site 8 (upstream reference site), site DN1 is equivalent to site 3 (5 km downstream) and site DN2 is equivalent to site 1 (23 km downstream). The spring and summer samples in both studies were very close together, the sample sites were fairly close and the techniques used were also similar, so there is reasonable confidence that the results should be comparable (Table 5). Himbeault's spring samples showed high percentages of EPT in the upstream and first downstream site, while samples from this study showed highly variable numbers. This pattern was reversed in the summer and autumn samples, with the percentage of EPT being consistently higher in samples from this study. Also, the numbers of individuals in each sample varied widely between studies, to the point where confidence in the comparability of the studies was greatly reduced. In Himbeault's October samples at DN1 and 2, the presence of mayflies (*Baetis sp.*) and caddisflies (*Hydropsyche sp.*) was totally overwhelmed by massive numbers of midges (Chironomids in general).

Table 5. Percentage of EPT in Samples

	Spring		Summer		Autumn	
	Himbeault	**This Study**	**Himbeault**	**This Study**	**Himbeault**	**This Study**
Upstream	0.89	0.39	0.29	0.77	0.10	0.64
Down 1	0.96	0.02	0.13	0.22	0.05	0.86
Down 2	0.11	0.25	0.32	0.48	0.03	0.40

The differences between the two studies are fairly subtle. Himbeault found mayflies, caddisflies and midges in high to extremely high abundance at the three comparable sites. Those mayflies and caddisflies found in his study were almost exclusively of the genera *Baetis* and *Hydropsyche*, respectively. They are not considered to be very sensitive to pollutants (Chandler 1970; Klemm et al. 1990). Sensitive species of case-building caddisflies (*Oecetis sp.* and *Hydroptila sp.*) were found in both studies. The presence of pollution-sensitive mayflies in samples from this study that do not appear in Himbeault's include *Ephemeralla inermis*, *Hexagenia limbata*, *Brachycercus prudens*, and *Centroptilum bifurcatum*. Pollution-sensitive stoneflies (*Isoperla sp.* and *Acroneura abnormis*) were rarely found in Himbeault's study, but were found more often in this study. In Himbeault's data there was a tendency to lose sensitive mayflies at the first downstream sampling station compared to the upstream station. The massive presence of flies and midges in Himbeault's study may point to less competition from other types of benthic invertebrates due to the sewage treatment plant.

Reynoldson (1973) studied the benthic macroinvertebrates on the Old Man, Bow, Red Deer and North Saskatchewan rivers in Alberta above and below sewage outfalls. In those locations where the downstream sampling site was relatively close to the sewage outfall there was a very definite change in the benthic invertebrate community structure. The numbers of species declined considerably, especially amongst the mayflies and caddisflies. A few species became dominant in the samples, typically worms (Oligochaetes) and midges (Chironomids). The community structure typically returned to pre-discharge numbers within 20 km of the outfall.

Golder Associates (1995) conducted a detailed survey of the North Saskatchewan River in Edmonton. There were very obvious effects on the invertebrate populations from the Gold Bar WWTP that serves Edmonton. Benthic invertebrate monitoring documented severe benthic community alteration downstream of the outfall, caused by organic enrichment. The large increase in Oligochaetes (Tubificidae and Naididae), followed by chironomid (Chironomini, Orthocladiniinae, Tanytarsini, and Tanypodinae) dominance, are typical effects of strong nutrient enrichment. A substantial increase in the abundance of pollution-tolerant oligochaete worms generally occurs in this zone at the expense of sensitive taxa, which tend to be excluded. Farther downstream, the large increase in benthic algal biomass resulting from increased nutrient levels leads to chironomid dominance followed by a gradual return of more sensitive invertebrates. Moderately enriched far-field areas may support dense populations of chironomids (Orthocladiniinae and Chironomini), net-spinning caddisfly larvae, and certain mayfly nymphs. Stonefly nymphs (families Chloroperlidae and Perlodidae) generally recover the farthest from WWTP outfalls. The abundance of these invertebrates in the North Saskatchewan River did not return to upstream levels within the 65 km of the study area. Water boatmen (*Callicorixa*) became abundant in areas with extensive growths of attached macrophytes that provided good habitat for them (Golder Assoc. 1995). The longitudinal pattern in invertebrate abundance and community composition in the study reach is largely indicative of nutrient enrichment contributed by municipal WWTPs. Due to inputs of organic matter and nutrients, sedimentation, and plant growth on the river bed substrates in and downstream of Edmonton, the zoobenthos changed from an assembly of clean-water taxa (dominated by certain species of stoneflies, mayflies, and caddisflies) at Devon to a less diverse and more abundant fauna characterized by pollution-tolerant taxa (such as Oligochaetes and Chironomids) below Gold Bar (Anderson et al. 1986).

Perrin et al. (1988) found similar changes in the benthic community of the Cowichan River on Vancouver Island following the discharge of sewage effluents to a previously unaffected river. The abundance of mayflies, caddisflies and stoneflies was reduced and densities of Oligochaetes and Cladocerans increased below the discharge point. The Cladocerans likely responded the growth of algal mats below the discharge. Otte and Levings (1975) found a similar pattern on an intertidal mudflat in the Fraser River estuary close to a sewage outfall. Oligochaetes and a polychaete worm dominated the community in an affected zone near the outfall that was characterized by the absence of oxygen due to the high BOD of the sediments, poor water exchange, soft organic rich sediments and high settling rate of the particulates in the sewage. At an intermediate distance there was a biostimulation effect, characterized by increased abundance of most of the organisms found in unaffected areas.

4.1.6 Summary of Benthic Invertebrate Data

In summary, some characteristics of the benthic invertebrate data are evident. The first is that there are no discernable patterns to the Diversity or Biotic Score data either between the reference site and the downstream sites, or between dates at each site. Two sites (2 and 5) at first seemed to be of a different habitat type, being more of a depositional nature with more sediment and fewer rocks; however, their populations of benthic macroinvertebrates did not bear this out.

Second, the Diversity Indices and Biotic Scores are almost uniformly high; out of 32 samples, only six could be considered low. Diversity and Biotic Scores are not well correlated, as they are measuring different characteristics of the benthic invertebrates.

Third, the numbers of individuals and the number of species present throughout the summer and in all sites are generally high and the community at each site is dynamic.

Fourth, the benthic invertebrate data have not identified any unusual patterns in abundance. Many species are present in higher numbers at certain times and then are depleted or totally absent. This would be expected as the aquatic forms of many insects mature, emerge to mate and lay eggs and are absent from the area for a period of time. *Ephoron album*, a mayfly, is present up to August and then is largely absent as the mayflies emerge in August to mate (Lehmkuhl 1976). One of the more interesting patterns of this type was the sudden and nearly ubiquitous appearance of *Cambarincola sp.*, a species of leech-like worms that are commensal on crayfish. Coincident with the appearance of this species was an increase in the population of crayfish *Orconectes virilis* as the eggs had hatched (a female carrying eggs was captured on June 13) and the young were maturing.

The fifth characteristic is the presence, even immediately below the outfall at site 7, of pollution-intolerant species of the orders Ephemeroptera, Plecoptera and Trichoptera. Pollution-tolerant species are also well represented, but coincident with pollution-intolerant species as would be expected in relatively unaffected communities.

Based on the high Diversity and Biotic Scores shown by the benthic macroinvertebrates and the lack of any discernable pattern of presence or abundance between the upstream reference site and the downstream sites, it must be concluded that the Saskatoon sewage effluents do not affect the benthic fauna of the river. This does not mean that they are living under pristine conditions, for Lehmkuhl (1972) detected significant alterations of the benthic invertebrate fauna from the Garrison Dam 150 km upstream of Saskatoon. The benthic invertebrate fauna had not returned to pre-dam abundance or types by Saskatoon, but he did not continue his investigations past the sewage outfall. However, the organisms that he found immediately above Saskatoon were very similar to those found in this survey.

4.2 Macrophytes

Several researchers over the past 20 years have identified excessive macrophyte growth below the sewage treatment plant as being problematic (Tones et al. 1980; Chambers 1993; City of Saskatoon 1985).

Tones et al. (1980) took note of macrophyte abundance while conducting periphyton sampling in 1976 and 1977. The study noted that the abundance of macrophytes above and to the east of the effluent plume was "none to slight"; as well, the abundance immediately below the outfall was "slight". With increasing distance downstream the abundance increased to the point where at Hague Ferry in 1977 they were "very abundant". "The impact of the Saskatoon sewage treatment plant on weed growth is important and extends for at least 80.9 km downstream."

The City of Saskatoon conducted detailed measurements on macrophyte biomass below its sewage treatment plant in 1984–1985. Dry weight biomass at Clarkboro Ferry varied from a range of 488–2800 g/m^2 in 1984 to a range of 134–405 g/m^2 in 1985. Other locations upstream of the Ferry had higher densities. The City of Saskatoon undertook a synoptic survey of macrophytes in the river in 1984 and 1985. It reported dry biomass of submerged plants averaging 99–1398 g/m^2 in the 47-km reach downstream of the sewage treatment plant. The dominant species were *Potamogeton pectinatus*, *P. filiformis* and *P. vaginatus*. Chambers (1993) conducted a similar assessment and found maximum summer (late July–early August) biomass of submerged plants ranging from 0.5–1030 g/m^2 dry mass. Biomass generally peaked below Clarkboro Ferry, but was still heavy in many spots above the Ferry.

Chambers (1993) and Carr and Chambers (1998) investigated nutrient dynamics in the South Saskatchewan River at Saskatoon to determine the cause of the excessive macrophyte growths. In an experiment Chambers showed that in the South Saskatchewan River, the type of sediment was a major factor in the presence or absence of *Potamogeton crispus*. The causative factor was phosphorus concentration in the sediment. Carr and Chambers (1998) found that macrophyte biomass increased linearly with increasing sediment P concentration, but not to sediment N concentration. Nitrogen concentration in plants was correlated with N concentration in the water, but not the sediments. This showed that sediments are crucial to the macrophytes in the river, and that water chemistry was secondary to their growth.

Chambers (1993) also showed that reduction of submerged plant growth in the South Saskatchewan River below Saskatoon was related to river discharge. River flows during June and July of 1990 and 1991 were relatively high, peaking at 769 and 587 m^3/s—approaching pre-regulation norms and greatly in excess of the post-regulation monthly averages of 255 and 245 m^3/s, respectively. Flow rates in July and August 1993 peaked around 924 m^3/s. In 1995 a massive flood occurred in the South Saskatchewan River basin; flow rates at Saskatoon peaked in June at 1280 m^3/s, then dropped to around 400 m^3/s for a few weeks but rose again to 850 m^3/s in July. Under high flows the fine, nutrient-rich sediments were scoured, reducing or eliminating submerged macrophytes all together. The poor growth of macrophytes in 1992 was likely due to scouring of sediments in 1990 and 1991. The flood conditions of 1995 would likely have scoured the river bottom even more than the high flows of 1990–1991. Chambers (1993) estimated that flows in excess of 300 m^3/sec

appeared to prevent plant growth and that flows in excess of 100 m^3/sec would reduce them by about 25% of what occurs under low flow conditions (45 m^3/sec).

In this study we took note of macrophytes when and where we noticed them, which was not often. A few beds of macrophytes (identified as *Potamogeton crispus* by P. Chambers) were seen along the shore at sites 2, 5 and 8 in May. Small macrophyte beds were first noticed in June at sites 1, 4, 5, 6 and 8, with *P. crispus* being dominant and with a grass-like plant intermixed. By July a few beds of *P. crispus* were noted at site 1 along the left bank, and in a few sheltered spots upstream of site 1 on both sides of the river. *P. crispus* individuals measured roughly 1 metre in July at site 1; however, overall macrophyte growth was very limited from above the sewage treatment plant to Clarkboro Ferry. From June to August much of the riverbed was visible during boat trips and no macrophytes were in evidence except along the shores. The bottom of the river was alternately rocks and boulders or sandbars. The sandbars were also devoid of plants. No fine sediments were noticed except at sites 3 and 5, where the shore habitat was more depositional than erosional. This lends additional credence to the scouring hypothesis of Chambers (1993). The average percentage cover of the reach from the sewage treatment plant to Clarkboro Ferry for May to August 2000 would be less than 1%. It is likely that this lack of submerged plant growth is due to the large flood of 1995 scouring the sediments from the river, and to the reduction in nitrogen releases from the upgrade to the Saskatoon sewage treatment plant in 1996. Whether one factor or both are responsible is not possible to say from this study.

4.3 Periphyton

We sampled periphyton as a routine measure at each station. Raw data from the Chl-*a* samples are presented in Appendix III. The amount of periphyton present was expressed as mg Chl-*a*/m^2 of surface area sampled. Figure 18 shows the chlorophyll-*a* values. Some trends in the data are noticeable, in particular that the concentration of Chl-*a* increases from May to July or August for most sites. Site 5 is an anomaly in that Chl-*a* does not increase and seems to drop after June. Site 7 shows an apparent enrichment phenomenon, likely due to the residual nutrients in the sewage effluents. Algal growth at this location appears to be greater than anywhere else and increases from near 0 in May to over 2000 mg/m^2 in August. This enrichment trend is particularly noticeable in June and August. Chlorophyll-*a* values decline rapidly downstream from Site 7, although they are still relatively high in July and August at most sites.

In general, there appears to be an enrichment of attached algae immediately below the outfall from the sewage effluents, although the amount of algae on the rocks at site 7 did not appear to be excessive. There was an overall decline in algal growth downstream from site 8. This may indicate sources of nutrients from the City of Saskatoon other than the sewage outfall. Site 5 is an anomaly with greatly reduced Chl-*a* values, as it was for the benthic invertebrates; this is likely due to a difference in habitat rather than an impact from the effluents. It was noted that site 5 was more of a depositional site, with more sediments and macrophytes than other sites.

The trends detected in 2000 were very similar to the trends noted by Himbeault (1995) from samples taken in 1992. Spring concentrations were low regardless of whether the samples were from above or below the outfall. By autumn (October), the station immediately below the outfall had the highest Chl-*a* concentrations (650 mg/m^2) with concentrations declining downstream. Overall concentrations of Chl-*a* were lower than in this study; however, this may be the result of differences in sample timing and sampling techniques, and may also reflect yearly variations in algal growth.

Tones et al. (1980) collected water samples for Chl-*a* analyses. Their results are not directly comparable to this study; however, most algae found in rivers are from the periphyton, so that general trends are comparable. They found that the maximum Chl-*a* concentrations were significantly higher at their sampling stations at 1.1, 4.8 and 14.3 km downstream of the outfall in the plume than concentrations upstream or out of the effluent plume. A 4–5 fold increase in Chl-*a* concentrations occurred at 4.8 km, but little or no increase occurred prior to this. The authors hypothesized that metal concentrations, in particular copper, could be limiting the growth of periphyton within this zone. Present copper concentrations in the effluent are not significantly different from upstream of the outfall.

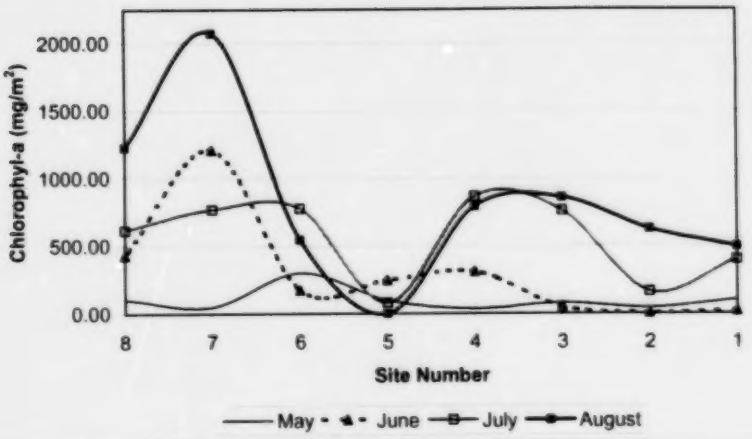

Figure 18. Chlorophyll-*a* Values

4.4 Chemistry Data

4.4.1 Water Chemistry

The Environment Canada labs in Edmonton and Saskatoon analysed for a full suite of water quality parameters (Table 6). Water samples were taken at each station in each month. In addition, in June, July and August a water sample was collected within 3 m of the outfall pipes to get a sample that was definitely within the effluent plume. Raw data from the water samples are presented in Appendix II.

Analyses of the samples was delayed due to the time it took to collect samples over two days and transport them back to Edmonton for analysis. Samples that included ammonia were field preserved with H_2SO_4, and samples that included sulphate were preserved with HNO_3. Samples were kept on ice for as long as possible and were stored in a cooler at 4°C until analysis. Even with these precautions it is possible that nutrients degraded within the sample containers, as there were very few detectable concentrations of nutrients in the samples when some were expected. The sewage effluents at release contained an average of 0.29, 0.12, 0.80 and 0.50 mg/L of ammonia for the months of May to August, respectively (Hwang 2000; Appendix V). This is reinforced by the pattern of Chl-*a* concentrations increasing at site 7 and slowly decreasing downstream, a pattern typical of nutrient enrichment.

The water quality samples showed very low levels of extractable metals, carbon, dissolved and suspended solids, and nutrients, regardless of month of sampling. Some parameters, such as TDS, Na, Mg, Ca and sulphate, show slightly increasing concentrations from site 8 to site 1, which is a natural pattern seen in unaffected rivers. Mineral concentrations that make up the bulk of the dissolved solids increase slowly downstream as more minerals are dissolved into the water column. There are no obvious increases in any parameters immediately below the outfall (site 7).

Nitrate was present above the effluent (site 8) in May and slowly increased downstream. There was very little nitrate present in June and July, while in August a low level of nitrate was present at site 7 (0.04 mg/L), with a higher concentration at site 1 (0.08 mg/L). This may be evidence of a slight continuing nitrification of ammonia in the river.

Table 6. Chemical Parameters in Water Samples and Detection Limits

Parameter	Detection Limit (mg/L)
Extractable Metals*	0.2 – 0.005
Total Organic Carbon, Inorganic Carbon, Total Carbon	<1
Bicarbonate and Carbonate Alkalinity	<1
Dissolved and Total Phosphorus	0.01
Sulphate	5
Total NO_x-N	0.03
Total Ammonia-N	0.02
Total Dissolved and Suspended Solids	<1

* Al, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, V, Zn

4.4.2 Comparison of Water Quality Samples with Other Studies

The City of Saskatoon provided its final process information as monthly averages from 1977 to 2000 in Appendix V (Hwang 2000). Tones et al. (1980), City of Saskatoon (1984), and Himbeault (1995) all analysed water samples around the City of Saskatoon sewage outfall.

Table 7. Inorganic and Metal Concentrations from City of Saskatoon (1985) and This Study

Parameter	Transect 4 (140 m dwnst) 1985 Mean (mg/L)	Site 7 June–Aug. 2000 Mean (mg/L)
Al	0.17	0.07
Ba	0.081	0.08
Be	0	< 0.001
Cd	0	< 0.004
Ca	46	42.20
Cr	0	< 0.006
Co	0	< 0.005
Cu	0.006	< 0.005
Fe	0.17	0.08
Pb	0.006	< 0.03
Mg	18	15.33
Mn	0.012	0.01
Mo	0	< 0.005
Ni	0	< 0.01
K	2.5	2.67
Na	25	24.23
Zn	0	< 0.005
$CaCO_3$	186	150.60
SO_4	67	66.67

Table 7 shows that there are few significant differences in inorganic chemicals immediately downstream of the outfall (transect 4 in 1985 and site 7 in 2000). The cations Ca, Na and Mg are reduced slightly; Al, Pb, Fe and hardness are also reduced somewhat.

The nutrients phosphorus, ammonia, nitrite and nitrate have been the focus of much of the pollution reduction work at the sewage treatment plant. Total and dissolved phosphorus were significantly above background concentrations in 1985, on average 5.13 mg/L (Hwang 2000), and did not return to background concentrations for over 150 km in summer (City of Saskatoon 1985). Following phosphorus precipitation in 1991, the concentration in the final effluent dropped to 0.96 mg/L in 1992. The phosphate and ammonia concentrations in the final effluent are presented in Table 8. PO_4 is presented as a yearly average, for cold temperatures do not affect it. NH_3 is presented as the summer average (March–August). The concentration of NH_3 in summer is much lower as the nitrification system works well when it is warm, and is a better reflection of the reductions achieved.

Table 8. Saskatoon Final Effluent Nutrient Concentrations 1995–2000

Year	Yearly Average PO_4 as P (mg/L)	Summer Average NH_3 as N (mg/L)
2000	0.35	0.31
1999	0.33	0.32
1998	0.38	0.36
1997	0.75	7.44
1996	1.09	18.07
1995	0.93	18.33

Saskatchewan Environment and Public Safety (Water Quality Branch 1989) conducted a survey of ammonia concentrations in the river. The survey found maximum ammonia concentrations of 4.26 mg/L 140 m below the outfall, at our site 7. Ammonia exceeded the Saskatchewan Surface Water Quality Objective (0.44 mg/L) for 5 kilometres (down to our site 3). Table 9 shows the means of summer samples for nutrients; the 1994–1995 data come from City of Saskatoon (1985). There have been significant decreases in the downstream concentrations of all nutrients. Ammonia is below detection limits in the river, while nitrates slowly build up in the river to slightly above background concentrations at Clarkboro Ferry 26 km downstream. Total phosphorus has been reduced over tenfold downstream of the sewage treatment plant and is now close to background concentrations.

Table 9. Nutrient Concentrations from 1994–1995 and 2000

	Summer Mean Concentrations (mg/L)							
	Upstream		140 m downstream		10–12 km downstream		26 km downstream	
	1994–1995	2000	1994–1995	2000	1994–1995	2000	1994–1995	2000
NH_3 as N	0.03	<0.02	0.06	<0.02	0.27	<0.02	0.18	<0.02
NO_2–NO_3 as N	0.03	<0.03	0.04	<0.03	0.46	0.05	0.24	0.06
TP	0.023	0.01	0.02	0.01	0.126	0.017	0.113	0.017

Improvements in effluent quality are very apparent in Table 10 (Hwang 2000). From 1977 to 1990 the average load of Total Suspended Solids (TSS) was 78 mg/L and BOD_5 was 107 mg/L. In 1991 the treatment plant started chemical precipitation of phosphorus, which also removed considerable quantities of TSS and some of the BOD_5. From 1977 to 1990 TSS concentrations were reduced 350% while BOD_5 was reduced by 33%. The 1996 upgrade reduced these values even further so that the average TSS concentration was reduced 244% and is now similar to that of the river (5–10 mg/L) and BOD_5 was reduced 700% to 10 mg/L.

Table 10. Reductions in Total Suspended Solids and Biochemical Oxygen Demand in the Saskatoon Effluents

Years	Average TSS (mg/L)	Average BOD_5 (mg/L)
1997–2000	9	10
1991–1996	22	72
1977–1990	78	107

4.4.3 Sediment Chemistry

Raw data from the sediment samples are presented in Appendix IV. Sediment chemistry did not reveal anything unusual either upstream or downstream of the sewage outfall. The one trend that was apparent was the concentration of phosphorus. Sites 8 and 7 typically contained around 330 µg/g (ppm) of phosphorus; the sediment concentration rose to 450 µg/g at sites 6 and 5 and then slowly dropped to 268 µg/g by site 1. Figure 19 shows the average sediment P concentration, as well as the 95% Confidence Limits and trend, based on May to July data. The August data were very different, with values at site 8 being barely detectable, and greatly reduced at several other sites. For these reasons the August data were left out of the average

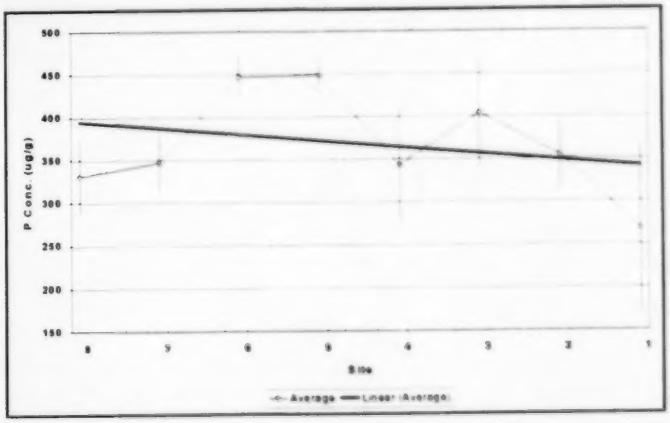

Figure 19. Average Sediment Phosphorus Concentrations (µg/g) with 95% CL and Trend Line

5. Conclusions

Macrophytes were noticeable only in small patches between the City and Clarkboro Ferry. This reduction in macrophytes is likely due to a coincidental scouring of the fine sediments by floods in 1991, 1992 and 1995, and the reduction in nutrients and TSS from sewage effluents in 1996. If scouring of macrophytes occurred in 1991 at flow rates of 795 m^3/s, then prior to the construction of the Gardiner Dam plant growth in the river would have been routinely scoured every few years. The massive macrophyte growths observed in the river may have been caused by a combination of consistently low flows from the Gardiner Dam, excessive nutrients, and suspended solids from the Saskatoon sewage treatment plant. The suspended solids would eventually have settled out in the river, contributing to the build-up of fine sediments. The flow rates are not likely to change significantly in the future; however, the nutrients and suspended solids have been largely eliminated

from the river water. The remaining sediments contain plenty of phosphorus, so whether the macrophytes will make a comeback remains to be seen and may depend largely on the deposition of sediment for rooting. Sources of fine sediment however have been reduced due to the Gardiner Dam trapping silt and the upgrade to the sewage treatment plant removing suspended solids. This survey did not continue past Clarkboro Ferry; however, the heaviest macrophyte growths identified in previous years were downstream of the Ferry. Any future surveys should include a macrophyte survey down to the confluence of the North and South Saskatchewan rivers.

Benthic invertebrates were diverse and abundant throughout the river below the sewage outfall, with no sign of an adverse impact on their numbers or community structure. Many of the attached species of stoneflies and caddisflies successfully used the algae covering the rocks as cover. Comparisons with a prior study showed some increase in the presence of sensitive insects. Comparison with other sewage-affected rivers in western Canada showed none of the characteristic impacts on benthic invertebrates, attached algae or macrophytes.

Nutrients have been reduced considerably in the river. The finished effluent prior to discharge contained very little ammonia (0.12–0.8 mg/L); with the increased dilution from using all 12 diffuser ports, there was little to detect downstream. Nitrate is very low at the outfall and increases slightly towards Clarkboro Ferry, indicating some nitrification of ammonia is continuing. Total phosphorus concentrations in the river are roughly ten times lower than in 1984. Metals in the effluent are all at low concentrations. Total suspended solids have been reduced to concentrations equal to that of the river upstream of the outfall, and biochemical oxygen demand has been reduced from an average of 107 mg/L to 10 mg/L.

Chlorophyll-*a* analyses on periphyton indicate some continued enhanced growth close to the outfall, but based on visual inspection the periphyton was not excessive. Periphyton growth declines downstream, presumably due to the extraction of the remaining nutrients.

Overall the South Saskatchewan River appeared to be very clean and little affected within the first 26 km of the river downstream of the City of Saskatoon's sewage effluent.

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Appendix I. Benthic Macroinvertebrate Data

Location	26km	10km	5km	2km	1km	500 m	150 m	100m up	26km	10km	5km	2km	1km	500 m	150 m	100m up
Month	**May**	**May**	**May**	**May**	**May**	**May**	**May**	**May**	**June**	**June**	**June**	**June**	**June**	**June**	**June**	**June**
Day	**24**	**24**	**24**	**24**	**24**	**25**	**25**	**25**	**14**	**14**	**14**	**14**	**13**	**13**	**13**	**13**
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
NEMATODA																
Mermithidae									1	16	2	10	1	3	8	5
OLIGOCHAETA																
Limnodrilus sp.	50	87	663	52	75	61	78	48	48	213	31	28	66	33	15	60
Nais sp.	2	19	142	1		2	4		1	81	4	11		4	1	4
Pristina aequiseta		1														
Tubifex tubifex	10		20							8		1	3	3	2	5
Uncinais uncinata	1		14							1						
BRANCHIOBDELLIDA																
Cambarincola sp.									2				1			
CLADOCERA																
Daphnia sp.											3	4		1		4
COPEPODA																
Acanthocyclops sp.															2	
Epischura sp.										1	84	69		6	2	96
AMPHIPODA																
Hyalella azteca							1	1								
OSTRACODA																
Candona sp.													1		1	
DECAPODA																
Orconectes (G.) virilis									2				2			
ARACHNIDA																
Atractides sp.												4		1		1
Lebertia sp.											1	4				1
COLLEMBOLA																
Isotomurus (s.s.) tricolor			1													
ODONATA																
Ophiogomphus severus	1					1			1	1		1	4			
EPHEMEROPTERA																
Baetis sp.	12	12					1	7	44	116	448	340	26	43	4	57
Brachycercus prudens			1							6			2	8	5	1
Caenis sp.			4							2				1		
Centroptilum bifurcatum			1						2	4		2	7	6	15	2
Ephemerella inermis	3	1	1				1	1			1	3				
Ephoron album									4	5	8	6				
Heptagenia sp.		1				1			30	3	33	225	10	1	1	1
Hexagenia limbata			3					1					2		2	
Leptophlebia cupida						1										
Metretopus borealis													2	1		1
Procloeon sp.									1	1		1	1		3	
Stenacron interpunctatum									4							

Stenonema terminatum	2	18		1		5	22	6	6		11	8	14		1	
Tricorythodes minutus	2	1	5			1	3			3	5	4	4		1	1
PLECOPTERA																
Isoperla bilineata	1	1			1	1		5				1			1	
TRICHOPTERA																
Ceraclea sp.									2							1
Ceratopsyche sp.	6	22	4	19		24	39	13	11	7	224	183	35	9	2	5
Cheumatopsyche sp.									1		2	4	1			
Hydropsyche valanis	3	3	1	3		2	9		5		17	15	20	21	5	
Hydroptila sp.	1							1								
Oecetis avara	1						2					1			1	
Polycentropus sp.									2					1		
Psychomyia flavida	17	11	1	6					42	1	24	4	1			
COLEOPTERA																
Trachyphloeus aristatus	1	1		1							2					
DIPTERA: Ceratopogonidae																
Probezzia sp.			3	1		1	2	3							1	
Chironomidae																
Tanypodinae																
Conchapelopia telema							1		2	3		6	6		2	
Hayesomyia senata		1				1		2	10		18	8	6	3	2	1
Procladius sp.			2													
Rheopelopia sp.1 Roback	9	3				1	2	3	4	2	11	24	5	6		1
Diamesinae																
Potthastia longimana			1							1						1
Orthocladiinae																
Brillia flavifrons											1					1
Corynoneura sp.									1							
Cricotopus sp.	3	13		3		2	1	6	5	10	33	51	7	15	6	13
Epoicocladius flavens													1			
Nanocladius sp.							1	3		1	8				1	
Orthocladius sp.		7				7	20	12		14	3				1	8
Paracladius alpicola							1								1	
Pseudosmittia sp.		1														
Synorthocladius semivirens						1		3	1		3	6	2	9	2	1
Tvetenia vitracies		1						1		1	58	52	5	6		2
Chironominae: Chironomini																
Chironomus sp.	1	1	944	4		30	13		1	1	1		1	2	11	4
Cryptochironomus sp.	7	8	7	1	4	10	13	10		7		4	6	1		4
Cyphomella gibbera										5				1	1	
Demicryptochironomus sp.	2	1									2					
Microtendipes caducus	8	2					1	2	3	4	7	62	4	3	1	
Paracladopelma nereis																2
Paratendipes albimanus		1	65	1		7	7	1		1						1
Phaenopsectra obediens			5	3		5	1		3			6	1	1	1	
Polypedilum sp.	40	29	51	28		17	26	7	26	7	33	43	3	8		7

Stenochironomus hilaris											1					
Xenochironomus xenolabis											1					
Chironominae: Tanytarsini																
Cladotanytarsus sp.	72	5	7	3		3	24	3	22	28	9	30		4		10
Micropsectra sp.			1													
Paratanytarsus sp.		7							1			1		3		
Stempellinella sp.			1				1								1	
Tanytarsus sp.		1	8			2			2	11		4	1	6	9	1
Empididae																
Hemerodromia sp.		1				1	1		1			7	2	3	2	
Simuliidae																
Simulium sp.		2								1	21	9	1	1		1
Tabanidae																
Chysops sp.													1			
GASTROPODA																
Ferrissia rivularis	4	3		1		1		1	1			3		1		
Physa sp.	1		1			1										
Valvata tricarinata	6								1							
BIVALVIA																
Musculium sp.	3								2							
Pisidium sp.	11	5	3	11	31	12	10	1	5	4		1	16	4		
Sphaerium simile	1															1

Location	**26km**	**10km**	**5km**	**2km**	**1km**	**500m**	**150m**	**100m up**	**26km**	**10km**	**5km**	**2km**	**1km**	**500 m**	**150m**	**100m up**
Month	**July**	**July**	**July**	**July**	**July**	**July**	**July**	**July**	**Aug**	**Aug**	**Aug**	**Aug**	**Aug**	**Aug**	**Aug**	**Aug**
Day	**12**	**12**	**12**	**11**	**11**	**11**	**11**	**11**	**23**	**22**	**22**	**22**	**22**	**23**	**23**	**23**
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
NEMATODA																
Mermithidae	4	9	3	28	1	2	2	1	15		1	1			1	4
OLIGOCHAETA																
Chaetogaster limnaei													1			
Limnodrilus sp.	28	310	7	61	154	25	120	31	89	47	3	8	24	67	1	7
Nais sp.	109	18	38	225	9	9	8	4	97	36	1	6	2	2		2
Pristina aequiseta									6	1					1	
Tubifex tubifex	9	14		7	86	6	2	6	19				30	4		
Uncinais uncinata	1	1		1			1		3	1						
BRANCHIOBDELLIDA																
Cambarincola sp.	9								12	6	87			6	21	39
HIRUDINEA																
Desserobdella picta					1											
CLADOCERA																
Daphnia sp.			1	2							7					
COPEPODA																
Acanthocyclops sp.									1					1		
Epischura sp.			3					1			3	1				1
AMPHIPODA																
Hyalella azteca	1			1					25							1

OSTRACODA																
Candona sp.	1															
DECAPODA																
Orconectes (G.) virilis	2			2					1	2	2	1		2	1	1
ARACHNIDA																
Lebertia sp.		1	1					1			1					
Torrenticola sp.			1								22					
COLLEMBOLA																
Isotoma sp.								1								
EPHEMEROPTERA																
Baetis sp.	1	1	184	12				9	8	1	21	2				2
Brachycercus prudens				1												
Caenis sp.	17	1		13	2	1	9	5								
Centroptilum bifurcatum	3	9				1			23						2	
Ephoron album	11	1	127	9				5			2					
Heptagenia sp.	6		20	11		17					2	2				
Hexagenia limbata					4								5			
Procloeon sp.		1	1											1		
Stenacron interpunctatum									29			6		17		
Stenonema terminatum	23	2	2	7		2		4	21	8	65	48		50	11	12
Tricorythodes minutus	10	10	75	42	3		2	10	1		10	3			2	7
PLECOPTERA																
Acroneura abnormis			1								6					
HEMIPTERA																
Sigara trilineata	1			1	1					1			2			
TRICHOPTERA																
Ceraclea sp.						1								6		
Ceratopsyche sp.	7	3	365	21	2		1	4	4	8	453	53		3	10	3
Cheumatopsyche sp.		1	3						4	4	11	6			3	3
Hydropsyche valanis	1		10	1					1	4	113	25		2	1	5
Hydroptila sp.				3								1			1	2
Oecetis avara											13			1	1	9
Polycentropus sp.									1			2		1		
Psychomyia flavida	3	3	55	1					3	6	42	9		1		1
COLEOPTERA																
Gyrinus sp.					2											
Trachyphloeus aristatus																
DIPTERA Ceratopogonidae																
Bezzia sp.					1											
Culicoides sp.					1											
Probezzia sp.																
Chironomidae Tanypodinae																
Ablabesmyia annulata									1							
Conchapelopia telema	15	3	1	5			1	2	1		1			1		
Hayesomyia senata			1	1					1		5	6		6		
Procladius sp.													1			
Rheopelopia sp.1 Roback '81	3		6	4				6		3		3		2		2

Diamesinae																
Potthastia longimana	1			2												1
Orthocladiinae																
Brillia flavifrons																
Corynoneura sp.																
Cricotopus sp.	11	5	24	58	2	2	1	11	9	3	6	3	1			1
Epoicocladius flavens					3								1			
Nanocladius sp.			2	1				1		1	1			2		
Orthocladius sp.	2	4	2	24	1		2	10		1						1
Paracladius alpicola																
Psectrocladius simulans								1								
Pseudosmittia sp.																
Synorthocladius semivirens	1		3	2				2			1					
Tvetenia vitracies			59						2		38	4				
Chironominae: Chironomini																
Chironomus sp.		11		33	185	11	7	2	8	1			28	6		
Cryptochironomus sp.	3	7	3	9			2	7	10	4	2			3		
Demicryptochironomus sp.				1	1						1					
Microtendipes caducus	32		27	54			2	7	14	5	24	4		1		
Nilothauma babiyi										1						
Paratendipes albimanus				4	3											
Phaenopsectra obediens	2	1	1	3	3		1	1						1		
Polypedilum sp.	8	9	93	88	15	1	5	20	12	26	34	9			1	6
Stenochironomus hilaris																
Xenochironomus xenolabis																
Chironominae Tanytarsini																
Cladotanytarsus sp.	7	22	35	78			4	6	85	29	12	3			2	11
Micropsectra sp.					1											
Paratanytarsus sp.	1	1		3	3			1	1	1					2	1
Stempellinella sp.		2														
Tanytarsus sp.	2	6		11	4	1	3	4	1					2		2
Empididae																
Hemerodromia sp.							1	1		2	1					3
Simuliidae																
Simulium sp.			2						1					1		
Tabanidae																
Chysops sp.																
GASTROPODA																
Ferrissia rivularis	11	1		4		1			15	2	3	2		3		
Fossaria (s.s.) parva					1											
Gyraulus (s.s.) deflectus									4							
Physa sp.									10			1	8			
Valvata tricarinata	13								58							
BIVALVIA																
Anodonta grandis																1
Musculium sp.																
Pisidium sp.	23	15	1	34	77	2	5	2	41	4	2	8	12	15	1	5
Sphaerium simile	1								2					1		

Appendix II. Water Chemistry Data

Site	1	2	3	4	5	6	7	8
Date	May 24	May 24	May 24	May 24	May 25	May 25	May 25	May 25
Parameter (mg/L)								
Carbons								
IC	36	35	35	35	35	35	35	35
TC	46	46	44	45	45	48	46	46
TOC	10	11	9	10	10	13	11	11
Extractable Metals								
Al	0.06	0.08	0.09	0.06	0.08	0.06	0.08	0.06
Ba	0.086	0.089	0.083	0.086	0.083	0.084	0.083	0.083
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ca	46	45.8	45.5	45.5	44.4	43.5	43.4	42.2
Cd	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Cu	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fe	0.06	0.089	0.127	0.09	0.118	0.084	0.099	0.07
K	3	3	3	2	3	3	3	3
Mg	16.8	16.5	16.3	16.2	15.6	15.5	15.3	15
Mn	0.006	0.009	0.012	0.009	0.008	0.007	0.008	0.005
Mo	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Na	26.2	27.2	26.2	25.8	23.8	24.2	24.3	24.2
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Pb	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Major Ions								
CO_3 Alk	4	4	8	4	4	4	4	4
HCO_3 Alk	142	140	141	148	138	142	146	144
TP	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01
DP	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH_3-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03
NO_x-N	0.09	0.08	0.11	<0.03	0.08	0.08	0.07	0.07
Sulphate	68.1	69.2	69	68.2	67.1	74.4	65.9	65.8
Physical Parameters								
TDS	279	282	273	268	267	280	270	272
TSS	4	7	8	5	10	10	9	8

Site	1	2	3	4	5	6	7	8	Outfall
Date	14 Jun	14 Jun	14 Jun	14 Jun	13Jun	13 Jun	13 Jun	14 Jun	13 Jun
Parameter (mg/L)									
Carbons									
IC	35	35	35	35	35	35	35	35	35
TC	46	46	46	47	46	46	46	46	46
TOC	11	11	11	12	11	11	11	11	11
Extractable Metals									
Al	<0.03	0.03	0.06	0.05	0.04	0.04	0.04	0.04	<0.03
Ba	0.079	0.082	0.082	0.081	0.08	0.08	0.081	0.08	0.081
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ca	42.4	43.4	44.2	42.8	43	43.1	43	43	42.9
Cd	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Cu	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fe	0.034	0.078	0.084	0.066	0.05	0.059	0.07	0.068	0.061
K	3	3	3	3	3	3	2	2	3
Mg	15.7	15.6	15.8	15.4	15.5	15.5	15.4	15.4	15.2
Mn	0.009	0.015	0.014	0.011	0.009	0.011	0.012	0.012	0.009
Mo	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Na	26.3	27	27.2	26.7	24.9	25.4	25.4	25.5	25.2
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Pb	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn	<0.005	<0.005	<0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Major Ions									
CO_3 Alk	8	8	4	12	8	8	8	8	6
HCO_3 Alk	152	144	146	140	140	144	142	144	145
TP	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01
DP	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH_3-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
NO_x-N	0.04	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Sulphate	69.4	68.9	69.7	69.4	67.2	68.5	68.3	69	66.1
Physical Parameters									
TDS	270	272	276	276	268	266	268	260	269
TSS	8	12	14	11	8	8	10	8	8

Site	1	2	3	4	5	6	7	8	Outfall
Date	12 Jul	12 Jul	12 Jul	11 Jul	11 Jul	11 Jul	11 Jul	11 Jul	11 Jul
Parameter (mg/L)									
Carbons									
IC	31	34	34	34	34	34	34	34	35
TC	41	44	45	45	44	44	44	45	46
TOC	10	10	11	11	10	10	10	11	11
Extractable Metals									
Al	0.06	0.1	0.11	0.12	0.11	0.1	0.11	0.11	0.1
Ba	0.081	0.086	0.084	0.085	0.086	0.082	0.085	0.084	0.077
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ca	42.7	43.9	43.4	42.3	43.8	40.5	40.9	42.9	44.6
Cd	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	0.006	<0.006	0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Cu	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fe	0.057	0.114	0.125	0.118	0.111	0.116	0.119	0.121	0.112
K	3	4	3	2	3	2	3	2	4
Mg	16.8	16	15.8	15.4	15.5	14.6	14.8	15.1	17.5
Mn	0.007	0.013	0.016	0.016	0.016	0.015	0.017	0.016	0.034
Mo	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Na	25.6	25.5	25.7	25.2	24.4	24.2	24.1	24.3	33.4
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Pb	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn	<0.005	0.011	0.007	<0.005	0.029	<0.005	<0.005	0.022	0.025
Major Ions									
CO_3 Alk	14	12	10	10	10	7	8	8	4
HCO_3 Alk	121	133	134	132	138	140	142	140	149
TP	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.03
DP	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH_3-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
NO_x-N	0.07	0.09	0.1	<0.03	<0.03	<0.03	<0.03	<0.03	0.55
Sulphate	67.8	66.9	68.1	65.5	65.5	64.3	66.8	65.1	86
Physical Parameters									
TDS	258	270	260	258	262	258	257	262	310
TSS	9	6	14	10	15	5	14	8	10

Site	1	2	3	4	5	6	7	8	Outfall
Date	23 Aug	22 Aug	22 Aug	22 Aug	22 Aug	23 Aug	23 Aug	23 Aug	23 Aug
Parameter (mg/L)									
Carbons									
IC	33	33	33	33	33	33	33	34	33
TC	45	45	45	44	44	45	45	45	46
TOC	12	12	12	11	11	12	12	11	13
Extractable Metals									
Al	0.08	0.07	0.07	0.08	0.08	0.06	0.07	0.08	<0.03
Ba	0.079	0.08	0.079	0.082	0.08	0.082	0.08	0.081	0.005
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ca	37.9	42.4	43.1	43.4	44.2	44.1	42.7	42	0.04
Cd	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Co	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	0.009	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.009	<0.006
Cu	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Fe	0.075	0.067	0.06	0.069	0.067	0.06	0.055	0.072	0.002
K	3	3	3	2	3	3	3	3	<1
Mg	14.4	15.6	15.8	15.9	16.3	16.2	15.8	15.3	<0.01
Mn	0.012	0.007	0.007	0.008	0.009	0.009	0.006	0.009	<0.001
Mo	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	<0.005
Na	25.6	24.1	24.2	24	23.4	23.7	23.2	22.5	<0.5
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Pb	0.05	0.03	<0.03	<0.03	0.04	<0.03	<0.03	0.04	<0.03
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.007	<0.005
Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.007	<0.005
Major Ions									
CO_3 Alk	8	15	8	8	11	10	9	8	6
HCO_3 Alk	141	136	138	138	133	138	143	138	143
TP	0.02	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.09
DP	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.08
NH_3-N	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03
NO_x-N	0.08	0.06	0.07	<0.03	0.04	0.05	0.04	<0.03	0.57
Sulphate	68.2	66.6	65.9	68.7	68.1	68.1	64.9	64.6	79.2
Physical Parameters									
TDS	266	266	266	262	255	262	257	252	299
TSS	8	3	6	6	9	12	6	7	5

Appendix III. Chlorophyll-*a* Analyses

	Chlorophyll-*a* in area sampled (mg/m^2)							
	22 km	10 km	5 km	2 km	1 km	0.5 km	0.1 km	Upstream
Site	1	2	3	4	5	6	7	8
May	100.87	43.90	79.10	35.46	97.00	299.59	48.55	104.08
June	17.70	4.15	48.31	308.30	246.09	173.25	1208.22	429.46
July	399.12	162.95	759.85	863.86	79.40	777.95	769.14	614.11
August	494.16	624.50	857.50	790.64	0.07	545.77	2074.15	1228.03

Appendix IV. Sediment Chemistry

May

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Particle Size (mm)	Units	26 km	10 km	5 km	2 km	1 km	500 m	100 m	100 m up
0.00024	%	0	0	0	0	0	0	0	0
0.002	%	0	0.4	3	2.1	2	3.3	2.1	2.5
0.004	%	0	1.1	6.2	4.4	4	6.9	4.4	5.4
0.008	%	0	1.9	10.8	7.8	6.8	11.7	7.9	9.2
0.016	%	0	2.8	16.2	12	10.3	17.4	12.4	14
0.031	%	0	4.8	24.3	17.9	14.2	25.3	18	20.2
0.062	%	0	5.8	41	27.2	27.4	46.9	28.6	34
0.125	%	0	18.5	68.3	40.7	63.8	81.4	44.6	63.4
0.25	%	1.9	68.4	91.1	63.5	89.4	97.3	64	90.9
0.5	%	33.1	98.8	98	87.5	91.6	98.4	84.8	99.1
1	%	63.6	99.6	99	94.7	91.6	99.3	91.6	99.1
2	%	73.5	99.6	100	95.3	91.8	99.9	92.2	99.2
4	%	77.7	99.6	100	95.5	92.3	100	93.6	99.3
8	%	89	99.8	100	96	93.4	100	96.7	99.6
16	%	100	100	100	96.9	97.8	100	98.5	100
32	%	100	100	100	100	100	100	100	100
64	%	100	100	100	100	100	100	100	100
Metals									
Al	µg/g	1130	2360	4370	2710	3660	4570	3350	3760
Ba	µg/g	25.6	62.9	132	80.2	120	141	103	114
Be	µg/g	<0.1	0.1	0.3	0.2	0.2	0.3	0.2	0.2
Ca	µg/g	18000	20700	34900	25800	33000	40400	33700	33700
Cd	µg/g	<1	<1	<1	<1	<1	<1	<1	<1
Co	µg/g	<4	<4	6	4	4	6	5	5
Cr	µg/g	2.9	5.4	9.5	6.1	8.9	9.3	7.2	8
Cu	µg/g	2.5	1.8	8.4	5.2	5	9.2	7.7	6.3
Fe	µg/g	5380	6560	9880	7430	8080	10100	8440	9050
K	µg/g	200	400	900	500	600	800	600	700
Mg	µg/g	4300	4770	7480	5310	8410	8630	6540	7100
Mn	µg/g	137	182	267	199	223	282	240	258
Na	µg/g	70	90	140	100	120	120	120	110
Ni	µg/g	5	8	13	10	10	14	11	12
P	µg/g	201	316	427	325	445	437	357	377
Pb	µg/g	<5	5	8	8	8	11	10	8
V	µg/g	5.2	7.8	11.4	8.6	9.8	11.2	9.6	9.9
Zn	µg/g	12.2	22.4	40.2	27	31.1	43	34.5	36.7
S	µg/g	139	219	672	429	504	636	581	490
Particle Size Distribution									
Clay	%	0	1.1	6.2	4.4	4	6.9	4.4	5.4
Silt	%	0	4.7	34.8	22.8	23.4	40	24.2	28.6
Sand	%	73.5	93.8	59	68.1	64.4	53	63.6	65.2
Gravel	%	26.5	0.4	0	4.7	8.2	0.1	7.8	0.8
Carbon Analyses									
Carbon									
TC									
IC									
OC									

June

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Particle Size (mm)	**Units**	**26 km**	**10 km**	**5 km**	**2 km**	**1 km**	**500 m**	**100 m**	**100 m up**
0.00024	%	0	0	0	0	0	0	0	0
0.002	%	1.3	1.6	1.5	0.8	0.5	2.9	1.6	0.8
0.004	%	2.7	3.5	3.2	1.7	1	6	3.4	1.9
0.008	%	4.6	6	5.6	2.9	1.7	10.4	6.2	3.2
0.016	%	6.6	9	8.6	4.1	2.6	16	9.8	4.8
0.031	%	10	12.6	13.1	6.2	3.7	23.1	14.1	6.5
0.062	%	20.4	18.3	21.1	10.2	6.5	40	19.1	10.8
0.125	%	33.8	50.5	39.7	29.5	13.7	73.4	27.8	26.4
0.25	%	43.2	92.3	76.1	70.1	20.2	93	62.1	62
0.5	%	54	100	98.5	93.1	21.9	94.4	95.4	94.2
1	%	59.4	100	99.8	95.6	22.2	94.4	98.8	99.2
2	%	69.4	100	99.8	97.3	23.5	94.5	99	99.3
4	%	72.2	100	100	98.1	24.8	94.9	99.2	99.5
8	%	79.8	100	100	99.1	29.4	96.7	99.2	99.8
16	%	98.9	100	100	100	50	100	100	100
32	%	100	100	100	100	89.2	100	100	100
64	%	100	100	100	100	100	100	100	100
Metals									
Al	µg/g	3020	2960	2920	2030	3240	4170	2990	2480
Ba	µg/g	82.5	71	79	50	98.2	125	82.2	59.4
Be	µg/g	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2
Ca	µg/g	27100	26000	25500	19500	29400	38000	26500	20200
Cd	µg/g	<1	<1	<1	<1	<1	<1	<1	<1
Co	µg/g	4	5	5	<4	<5	5	5	4
Cr	µg/g	7	7.1	6.8	4.8	8.5	9.7	6.4	5.9
Cu	µg/g	5.3	4.8	4.6	2.8	5.8	7.9	6	3.7
Fe	µg/g	7510	7690	7740	5970	7440	8930	8800	6940
K	µg/g	600	500	500	300	600	800	500	400
Mg	µg/g	6330	6500	5500	4480	7080	8380	4760	4810
Mn	µg/g	181	184	213	152	221	250	250	171
Na	µg/g	150	110	130	90	130	140	120	110
Ni	µg/g	11	12	11	9	9	12	12	10
P	µg/g	364	381	342	295	430	431	312	301
Pb	µg/g	6	9	8	29	7	9	9	6
V	µg/g	8.3	8.5	8.9	7.1	10.5	10.4	9.9	8.2
Zn	µg/g	26.7	29.2	28.4	19.9	31.2	38.6	33.1	23.8
S	µg/g	418	383	342	267	487	585	598	282
Particle Size Distribution									
Clay	%	2.7	3.5	3.2	1.7	1	6	3.4	1.9
Silt	%	17.7	14.8	17.9	8.5	5.5	34	15.7	8.9
Sand	%	49	81.7	78.7	87.1	17	54.5	79.9	88.5
Gravel	%	30.6	0	0.2	2.7	76.5	5.5	1	0.7
Carbon Analyses									
Carbon									
TC									
IC									
OC									

July

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Particle Size (mm)	**Units**	**26 km**	**10 km**	**5 km**	**2 km**	**1 km**	**500 m**	**100 m**	**100 m up**
0.00024	%	0	0	0	0	0	0	0	0
0.002	%	0.3	0.9	2.7	2	2.9	4	2.2	0.9
0.004	%	0.7	2	5.5	4.2	6.1	8.3	4.7	2
0.008	%	1.3	3.5	9.6	7.4	10.5	14.8	8.4	3.4
0.016	%	2	5.3	14.6	11.2	16.6	23.4	12.8	4.9
0.031	%	2.5	7.7	21.3	16.1	23.8	33.2	18.2	7.2
0.062	%	4.4	11.4	32.7	23.8	37.6	51.2	27.6	11.1
0.125	%	4.9	27.4	54.3	40.8	69.9	80.8	43.4	27.9
0.25	%	14.5	56	81.8	67.2	95.6	96.9	68.1	70.5
0.5	%	69.6	66.8	95.1	86.7	99.2	98	91.5	98
1	%	90.5	66.8	96.5	92.7	99.2	99.1	96.7	99.3
2	%	92.1	66.8	97.3	95	99.4	100	97.1	99.3
4	%	92.9	66.9	97.7	95.7	99.7	100	98.1	99.4
8	%	95.1	68	98.2	96.4	100	100	100	99.4
16	%	100	68.8	100	98.8	100	100	100	100
32	%	100	68.8	100	100	100	100	100	100
64	%	100	100	100	100	100	100	100	100
Metals									
Al	µg/g	1380	2900	3380	3030	3910	5190	3110	2270
Ba	µg/g	33.2	77	103	84.3	115	147	83.2	61.2
Be	µg/g	<0.1	0.2	0.2	0.2	0.5	0.3	0.2	0.1
Ca	µg/g	16300	25300	31900	27700	39300	50400	29800	20000
Cd	µg/g	<1	<1	<1	<1	<1	<1	<1	<1
Co	µg/g	<4	5	5	<4	5	5	4	4
Cr	µg/g	3.7	6.6	7.3	7	9.4	10.6	7.6	5.8
Cu	µg/g	1.5	5	7.8	5.4	8.9	12.3	6.3	2.9
Fe	µg/g	4840	7720	8740	7570	9150	10900	8320	6520
K	µg/g	200	500	600	500	800	1000	600	400
Mg	µg/g	3710	5720	6910	6080	8360	9450	6500	4610
Mn	µg/g	132	211	249	196	250	314	200	178
Na	µg/g	120	110	170	180	200	210	160	<50
Ni	µg/g	6	10	12	10	12	14	11	9
P	µg/g	240	368	442	410	471	473	373	316
Pb	µg/g	<5	8	8	8	12	14	10	<5
V	µg/g	5.1	9	9.5	9.1	11	12.7	9.9	7.8
Zn	µg/g	15.2	30.8	39	30.1	43.9	58.3	40.7	25.6
S	µg/g	221	380	556	452	819	1003	568	254
Particle Size Distribution									
Clay	%	0.7	2	5.5	4.2	6.1	8.3	4.7	2
Silt	%	3.7	9.4	27.2	19.6	31.5	42.9	22.9	9.1
Sand	%	87.7	55.4	64.6	71.2	61.8	48.8	69.5	88.2
Gravel	%	7.9	33.2	2.7	5	0.6	0	2.9	0.7
Carbon Analyses									
Carbon									
TC									
IC									
OC									

August

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Particle Size (mm)	**Units**	**26 km**	**10 km**	**5 km**	**2 km**	**1 km**	**500 m**	**100 m**	**100 m up**
0.00024	%	0	0	0	0	0	0	0	0
0.002	%	2.7	0.4	2	1.9	5.9	0.4	0.5	0
0.004	%	5.6	1.1	4.3	4	12.6	0.9	1.2	0
0.008	%	9.6	2.1	8.1	6.9	23.1	1.8	2.2	0
0.016	%	13.8	3	12.9	10.5	36.8	2.5	3.2	0
0.031	%	20.8	4.6	18.1	15.1	51.6	3.9	4.8	0
0.062	%	41.7	5.5	22.8	21.2	66.2	5.9	6.8	0
0.125	%	67.1	10	34.6	29.8	80.1	6.5	9.5	0
0.25	%	76	53.4	66.8	42.3	92.3	52.9	50.6	8.2
0.5	%	81.1	88.8	93.2	51.2	97.5	98.3	96.5	62.5
1	%	84.4	90.6	98.2	52.8	98.2	98.9	99.6	97.4
2	%	85.5	90.9	99.2	53.3	99.7	99	99.8	100
4	%	86.4	92.9	99.4	54	99.9	99.1	100	100
8	%	88.7	98.8	100	54.5	100	99.4	100	100
16	%	96.1	100	100	55.7	100	100	100	100
32	%	100	100	100	55.7	100	100	100	100
64	%	100	100	100	100	100	100	100	100
Metals									
Al	µg/g	4220	2000	2780	4130	5940	1800	1840	10
Ba	µg/g	120	44.4	75.8	112	158	36.1	39.1	0.2
Be	µg/g	0.3	0.1	0.2	0.3	0.3	0.1	0.1	<0.1
Ca	µg/g	38200	18200	28300	41200	64700	14200	15900	129
Cd	µg/g	<1	<1	<1	<1	<1	<1	<1	<1
Co	µg/g	5	<4	5	5	6	<4	4	<4
Cr	µg/g	8.9	5.5	6.5	9.5	13.5	4.3	4	27
Cu	µg/g	11.8	2.6	6.5	14	28.5	2.2	3.4	34
Fe	µg/g	9450	6300	7620	9310	11500	5670	6430	38
K	µg/g	800	300	600	800	1200	300	300	1900
Mg	µg/g	8120	3800	4930	6860	9690	2950	2980	24
Mn	µg/g	221	162	226	263	329	143	176	1.1
Na	µg/g	130	70	120	150	230	70	70	<50
Ni	µg/g	15	10	11	13	16	9	10	68
P	µg/g	458	298	334	380	490	239	234	2
Pb	µg/g	10	6	9	16	22	6	8	<5
V	µg/g	10.5	7.6	8.9	11.4	14.8	6.8	7.3	40
Zn	µg/g	41.4	22.3	33	45.4	73.7	19.6	22.2	<0.5
S	µg/g	1070	279	507	744	1940	203	239	110
Particle Size Distribution									
Clay	%	5.6	1.1	4.3	4	12.6	0.9	1.2	0
Silt	%	36.1	4.4	18.5	17.2	53.6	5	5.6	0
Sand	%	43.8	85.4	76.4	32.1	33.5	93.1	93	100
Gravel	%	14.5	9.1	0.8	46.7	0.3	1	0.2	0
Carbon Analyses									
Carbon									
TC									
IC									
OC									

Appendix V. City of Saskatoon Final Process Data

CITY OF SASKATOON WASTEWATER TREATMENT PLANT FINAL PROCESS INFORMATION (monthly averages) 1977 - 2000						
	SEWAGE FLOW	BOD	TSS	PO_4 as P	NH_3 as N	NO_3- N
	(cu.m.)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
2000						
Jan	107,635	10	8	0.32	2.55	6.3
Feb	119,379	12	9	0.63	13.63	10.7
Mar	109,958	14	9	0.37	0.23	7.8
Apr	108,363	9	7	0.22	0.17	10.8
May	108,818	7	6	0.25	0.29	8.9
Jun	113,955	7	7	0.21	0.12	4.0
Jul	121,563	7	8	0.31	0.80	2.0
Aug	120,600	8	8	0.47	0.50	2.5
1999						
Jan	95,197	19	10	0.42	1.56	3.4
Feb	93,087	17	6	0.36	11.10	2.9
Mar	97,249	14	5	0.28	8.98	3.7
Apr	96,132	12	6	0.30	12.50	4.0
May	98,932	11	5	0.19	4.78	5.1
Jun	105,049	16	10	0.46	0.58	3.4
Jul	109,458	15	11	0.29	0.12	4.1
Aug	105,884	11	7	0.38	0.22	5.9
Sep	97,078	7	6	0.54	0.57	6.0
Oct	90,580	9	7	0.23	0.26	3.9
Nov	100,058	8	6	0.21	0.20	7.2
Dec	99,895	8	6	0.24	0.87	5.3
1998						
Jan	77,235	8	6	0.95	1.41	8.5
Feb	85,142	9	5	0.62	0.31	6.5
Mar	82,894	12	7	0.54	2.08	6.0
Apr	80,234	8	5	0.20	1.46	4.4
May	85,799	7	5	0.23	0.34	3.2
Jun	103,174	17	15	0.84	0.95	4.3
Jul	103,025	5	4	0.19	0.37	4.4
Aug	103,244	4	6	0.18	0.56	4.2
Sep	100,667	6	7	0.17	0.15	4.5
Oct	103,709	6	6	0.19	0.22	7.1
Nov	105,345	7	7	0.21	0.10	6.1
Dec	96,855	10	6	0.24	0.18	4.7

1997						
Jan	76,084	16	10	1.14	13.22	3.8
Feb	75,621	20	12	1.16	15.26	5.2
Mar	82,777	24	12	0.71	11.48	4.6
Apr	94,403	29	18	1.07	14.22	2.3
May	90,652	4	5	0.24	13.25	3.7
Jun	97,747	6	5	0.25	3.14	9.4
Jul	96,984	6	5	0.95	1.40	8.6
Aug	98,342	6	7	1.77	1.18	8.0
Sep	95,733	4	4	0.52	2.65	6.9
Oct	90,487	5	4	0.51	1.34	6.8
Nov	82,978	5	5	0.25	1.05	6.6
Dec	82,224	5	4	0.46	0.88	6.0
1996						
Jan	84,677	91	27	0.97	18.3*	
Feb	90,108	98	24	0.90	17.8*	
Mar	89,359	89	28	1.00	19.8*	
Apr	87,864	73	23	0.73	14.6*	
May	84,664	82	35	1.76	23.80	0.0
Jun	79,561	31	22	2.90	24.90	0.2
Jul	85,816	13	13	1.48	18.70	3.4
Aug	72,434	11	10	0.57	6.60	15.8
Sep	74,747	17	9	0.95	2.80	6.7
Oct	80,477	10	7	0.68	1.70	8.6
Nov	76,753	10	6	0.30	0.40	5.7
Dec	75,865	11	8	0.82	4.80	6.8
1995						
Jan	87,076	86	25	0.92	24**	
Feb	85,431	103	34	1.17	22**	
Mar	87,705	92	31	1.10	20**	
Apr	84,866	82	28	0.94	15**	
May	86,606	81	25	0.95	18**	
Jun	96,585	96	26	0.95	20**	
Jul	94,691	88	24	0.69	19**	
Aug	100,646	72	24	0.71	18**	
Sep	94,897	71	24	0.84	17**	
Oct	91,771	80	25	1.00	17**	
Nov	87,557	73	27	0.87	23**	
Dec	84,788	97	27	1.00	21**	
1994						
Jan	92,533	62	23	0.93		
Feb	88,923	74	27	1.24		
Mar	93,672	94	25	1.26		
Apr	86,669	91	18	0.90		
May	98,252	74	17	0.67		
Jun	106,645	71	26	0.86		
Jul	102,040	72	27	0.81		
Aug	100,951	76	26	1.03		
Sep	94,686	76	28	0.96		
Oct	91,291	87	24	1.09		
Nov	88,914	88	21	1.01		
Dec	87,462	93	21	0.94		

1993						
Jan	93,646	64	19	0.75		
Feb	88,498	77	22	0.92		
Mar	90,918	77	23	0.98		
Apr	90,128	88	21	0.93		
May	91,667	73	16	0.76		
Jun	98,388	70	16	0.72		
Jul	114,883	56	20	0.77		
Aug	103,218	55	22	0.97		
Sep	98,081	69	25	1.11		
Oct	90,789	73	25	1.06		
Nov	89,665	73	28	1.15		
Dec	87,089	79	26	1.08		
1992						
Jan	92,451	81	21	0.98		
Feb	95,728	78	21	1.01		
Mar	96,054	74	20	0.79		
Apr	92,520	82	20	0.92		
May	99,134	71	22	0.90		
Jun	99,876	68	21	0.78		
Jul	100,762	60	20	0.67		
Aug	98,782	55	19	0.69		
Sep	99,322	62	23	0.97		
Oct	94,023	77	20	0.95		
Nov	91,655	78	19	0.82		
Dec	88,394	78	23	0.96		
1991						
Jan	93,473	73	38	1.41		
Feb	94,672	85	32	1.26		
Mar	96,802	78	26	0.91		
Apr	97,998	81	18	0.66		
May	109,722	67	18	0.66		
Jun	122,502	74	21	0.61		
Jul	124,431	68	22	0.82		
Aug	110,602	78	23	1.16		
Sep	99,953	79	23	1.15		
Oct	96,553	93	24	1.19		
Nov	91,437	76	19	0.80		
Dec	90,262	81	17	0.86		
1990						
Jan	76,521	76	74	5.30		
Feb	78,875	94	83	4.88		
Mar	80,554	91	75	4.36		
Apr	85,375	77	77	3.78		
May	87,080	77	82	4.13		
Jun	91,684	76	85	3.62		
Jul	85,892	60	60	2.90		
Aug	96,832	60	53	2.71		
Sep	97,786	41	31	1.18		
Oct	99,574	60	34	1.56		
Nov	91,998	85	42	1.84		
Dec	83,296	72	30	1.13		

1989						
Jan	85,246	87	80	4.18		
Feb	85,142	85	92	6.14		
Mar	85,716	100	98	7.88		
Apr	82,466	100	70	6.87		
May	89,646	90	67	5.41		
Jun	91,437	73	72	5.04		
Jul	91,860	57	66	4.06		
Aug	88,898	59	68	4.08		
Sep	85,967	67	88	5.28		
Oct	78,618	75	96	5.97		
Nov	76,162	83	90	5.87		
Dec	74,805	74	72	4.64		
1988						
Jan	82,827	103	76	5.34		
Feb	81,876	94	73	5.78		
Mar	80,935	107	100	6.28		
Apr	79,269	102	82	6.45		
May	80,950	101	84	7.18		
Jun	87,497	84	74	5.98		
Jul	85,393	72	61	5.06		
Aug	88,150	64	53	4.21		
Sep	86,224	91	52	4.01		
Oct	84,264	87	48	4.27		
Nov	81,299	78	54	4.52		
Dec	77,225	85	73	5.97		
1987						
Jan	90,379	94	80	5.85		
Feb	94,786	87	67	4.86		
Mar	89,602	92	57	5.20		
Apr	82,299	93	65	5.62		
May	81,477	79	66	5.62		
Jun	85,921	81	71	4.63		
Jul	88,182	83	65	4.94		
Aug	84,894	65	43	3.74		
Sep	86,694	78	42	4.17		
Oct	87,945	88	49	4.78		
Nov	85,906	88	69	4.98		
Dec	81,668	98	87	6.02		
1986						
Jan	84,176	98	74	5.04		
Feb	82,758	101	94	5.38		
Mar	79,307	96	94	6.75		
Apr	76,451	104	96	6.24		
May	81,874	85	80	4.43		
Jun	87,345	75	73	5.17		
Jul	97,453	68	77	4.15		
Aug	86,552	70	76	4.65		
Sep	87,939	83	74	4.74		
Oct	87,241	72	71	5.26		
Nov	85,482	100	93	6.27		
Dec	82,328	102	91	5.68		

1985						
Jan	86,330	92	56	4.87		
Feb	84,736	100	70	5.30		
Mar	77,474	101	89	6.47		
Apr	77,071	99	84	5.20		
May	93,048	75	77	4.40		
Jun	69,873	82	74	4.74		
Jul	91,406	68	58	4.93		
Aug	93,216	65	63	3.99		
Sep	90,982	76	69	4.43		
Oct	82,006	72	78	5.13		
Nov	77,829	96	78	5.36		
Dec	73,603	102	81	6.74		
1984						
Jan	74,173	116	73	4.72		
Feb	70,185	125	72	4.84		
Mar	72,244	141	86	5.00		
Apr	68,557	144	89	5.86		
May	76,140	115	78	6.74		
Jun	90,255	111	71	3.53		
Jul	89,066	98	74	4.21		
Aug	91,185	106	63	4.87		
Sep	87,466	95	76	4.83		
Oct	84,440	103	71	5.23		
Nov	71,501	146	69	5.16		
Dec	76,417	107	74	4.80		
1983						
Jan	68,088	133	80	5.50		
Feb	66,1[illegible]	140	93	5.02		
Mar	65,27[illegible]	156	107	8.30		
Apr	65,949	139	80	5.75		
May	71,828	119	82	4.56		
Jun	82,981	100	78	4.29		
Jul	94,309	90	76	4.20		
Aug	89,778	52	59	4.35		
Sep	86,702	92	72	4.35		
Oct	79,116	121	70	4.38		
Nov	75,692	120	80	7.17		
Dec	72,312	139	77	4.58		
1982						
Jan	77,738	115	70	5.62		
Feb	74,101	131	81	5.10		
Mar	72,282	151	81	6.00		
Apr	71,828	146	88	5.50		
May	75,465	143	70	6.60		
Jun	75,465	122	69	5.28		
Jul	70,464	125	69	5.90		
Aug	75,920	108	62	4.75		
Sep	70,919	106	77	4.60		
Oct	70,009	113	67	6.00		
Nov	65,554	133	92	6.02		
Dec	63,190	142	85	5.42		

1981						
Jan	69,555	134	102	4.80		
Feb	68,646	127	89	5.70		
Mar	66,373	131	93	5.70		
Apr	65,464	127	92	7.30		
May	69,101	131	92	6.10		
Jun	66,827	113	71	6.00		
Jul	64,100	105	74	6.10		
Aug	77,283	95	73	4.70		
Sep	76,829	118	72	5.50		
Oct	75,920	114	71	4.90		
Nov	74,556	131	81	5.70		
Dec	70,010	142	76	7.20		
1980						
Jan	60,463	138	91	2.70		
Feb	62,736	85	85	6.60		
Mar	61,372	141	96	6.70		
Apr	62,282	137	97	6.20		
May	67,282	140	88	6.20		
Jun	85,466	126	84			
Jul	74,101	129	76			
Aug	75,920	121	78	4.90		
Sep	77,283	122	83	4.70		
Oct	73,647	130	85	5.60		
Nov	68,646	130	92	5.20		
Dec	72,283	138	96	6.00		
1979						
Jan	57,735	155	83	6.10		
Feb	58,190	145	76	6.70		
Mar	64,554	140	89	6.20		
Apr	63,645	131	92	5.60		
May	60,008	130	69	5.00		
Jun	57,735	120	76	4.90		
Jul	65,918	104	75	5.50		
Aug	69,555	110	88	7.30		
Sep	67,282	114	114	6.50		
Oct	65,009	126	79	7.40		
Nov	58,645	152	105	6.40		
Dec	58,490	134	93	5.90		
1978						
Jan	54,871	132	94			
Feb	63,145	137	96			
Mar	65,645	139	93			
Apr	64,418	143	96			
May	65,327	157	98			
Jun	74,874	136	85			
Jul	75,010	127	79			
Aug	74,738	125	79			
Sep	64,645	107	107			
Oct	53,871	104	91			
Nov	50,916	145	94			
Dec	49,416	148	86			

1977						
Jan	55,462	111	80			
Feb	50,462	125	88			
Mar	55,371	130	83			
Apr	54,917	128	88			
May	65,645	115	81			
Jun	69,464	120	87			
Jul	61,827	111	79			
Aug	62,236	117	83			
Sep	59,281	118	86			
Oct	55,416	111	101			
Nov	55,008	126	80			
Dec	50,280	128	93			

* From B. Clarke, City of Saskatoon, via M. Guy, Environment Canada, NHRI, Saskatoon, personal communication, 1998.

** From Environment Canada, Municipal Effluent Survey, 1998, for PSL2 assessment of ammonia in the aquatic environment, unpublished data.

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